CAPACITY AND QUALITY OF SERVICE FOR CDMA COMMUNICATION NETWORK WITH DIVERSITY & HANDOFF

A THESIS

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CANDIDATE' S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **CAPACITY AND QUALITY OF SERVICE FOR CDMA COMMUNICATION NETWORK WITH DIVERSITY & HANDOFF** in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in Department of Paper Technology of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from January, 2003 to November, 2006 under the supervision of Dr.S.C.Sharma, Associate Professor, Department of Paper Technology and Dr.Mohan Lal, Assistant Professor, Institute Computer Center of Indian Institute of Technology Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

The unabated growth in the use of wireless communication is continuing and new services are being introduced. The wireless users access or share to a resource using multiple access techniques. There are three multiple access techniques namely, Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA). FDMA is a technique whereby spectrum is divided up into frequencies and then assigned to users. The number of users are restricted by the number of available frequency channels. TDMA improves spectrum capacity by splitting each frequency into time slots. This allows each user to access the entire radio frequency channel for the short period of a call. Other users share this same frequency channel at different time slots. The number of users are restricted by the number of time slots in a frame. The CDMA is based on "spread" spectrum technology. It increases spectrum capacity by allowing all users to occupy all channels at the same time. Transmissions are spread over the whole radio band, and each voice or data call is assigned a unique code to differentiate from the other calls carried over the same spectrum. The number of users can be increased as large as the number of available orthogonal codes. The capacity of CDMA system is limited by interference. Capacity of a communication network is the maximum number of the subscribers that can be accommodated for a given quality of service parameters. The quality of service (QoS) parameters are signal to noise ratio, signal to interference ratio, bit energy to noise ratio and bit error rate etc.

Background of the problem

The CDMA has much attention for mobile communication systems because of its wide-band nature and inherent diversity in CDMA signal. The problem in the signal propagation is fading, which is a distortion that a carrier-modulated telecommunication signal experiences over certain propagation media. Short term fading is due to multipath propagation, and is also known as multipath induced fading. Fading results from the superposition of transmitted signals which have experienced differences in attenuation, delay and phase shift while traveling from the source to the receiver. The fading affects the quality of service parameters and in turn capacity of the system. Thus the problem in CDMA system is fading and interference.

The best way to combat fading is to ensure that multiple versions of the same signal are transmitted, received, and coherently combined. This is usually termed diversity, and sometimes acquired through multiple antennas.

In CDMA system, the multi-path fading can be resolved to become discrete fading signal branches due to wideband nature of the signal. The receiver exploits these multi-path diversity characteristics by diversity combining to mitigate the fading effect. The diversity combining is well recognized as an effective method to reduce fading effect and to enhance signal to noise ratio and thus to reduce the bit error rate. In CDMA system, there are three diversity-combining methods: Selection/Switched, Maximal ratio and equal gain combining and hybrid diversity combining.

When the mobile moves from the coverage area of one cell to the another, a new connection to/from the target cell has to be set up and the connection with the old cell has to be released i.e. soft handoff (Make before break). The signal from these two base stations can be combined to improve the signal quality and Quality of service parameters and consequently the improvement in capacity.

Objective of the present study /research work

The objective of the present research work is to study the performance of various diversity combining techniques in CDMA system that appeared in the literature and to modify the possibilities of enhancements for the existing model and further to apply fuzzy on diversity and handoff in CDMA system. The objectives are

- To explore the combined effect of antenna diversity and spread spectrum diversity on the bit error rate in CDMA system
- To study the bit error rate performance for the switched diversity using fuzzy logic to control the threshold
- To evaluate the performance of the soft handoff provided by the macro diversity due to two base stations simultaneously involved in communication.
- Performance analysis of the soft handoff algorithm using fuzzy technique

To fulfill the above objectives, the analysis is carried out as follows:

(I) To analyze the probability of bit error rate for combined effect of antenna diversity and spread spectrum diversity

In the literature, bit error rate for antenna diversity and spread spectrum diversity has been reported. In the present study the combined effect of bit error rate of spread spectrum diversity with maximum ratio combining (MRC) and antenna diversity with selection diversity using phase shift keying (PSK) has been discussed. The expression for the probability of bit error rate has been derived and the system bit error rate is determined in terms of Signal to Noise Ratio (SNR) requirement for each user. Results of the bit error rate shows that for uniformly distributed users a bit error rate improvement is obtained if a diversity connection is used in a cellular CDMA system.

(ii) To study the bit error rate performance for the switched diversity using fuzzy logic to control the threshold

The switched diversity combining is one of the diversity combining technique, in which the single receiver input is scanned in sequence to another signal whenever the receiver's output fades below a given threshold. Switching is performed at a threshold level, based on the channel conditions. The bit error rate expression has been used to analyzed for variation in SNR as described in literature. The fuzzy logic technique is applied to adjust the threshold (Th), at which switching is performed, based on the varying channel conditions like signal power (S), variation in channel state (ΔS). The output parameter of fuzzy inference system is ΔTh, which is used to modified switching threshold (Th). The bit error rate for the modified value of threshold has been analyzed.

(iii) To evaluate the performance of the soft handoff provided by the macro diversity

The Soft handoff capability provided by macro diversity in which a mobile is usually linked via multiple (typically two) signal paths to both the current base station and the target base stations. The signal to noise ratio is very weak in the soft handoff region. The signal to noise ratio (SNR) is improved by combining the signal from the different BS's. We have analyzed the effect of SNR on the system capacity. The capacity at the boundary without-macro diversity is calculated with different voice activity factor. The capacity of the system with macro diversity have been analysed and observed that it increases with increase in SNR in the soft hand handoff region. The effect of voice activity factor and interference factor on the system capacity is also evaluated.

(iv) Performance analysis of the soft handoff algorithm using fuzzy technique

Fuzzy handoff algorithm for wireless communication proposed by George Edwards et al has been applied to calculate the received signal strength (QoS) in macrocellular system. The parameter T_UP and T_Down, which dynamically vary, depending on the traffic load in each cell are used in the soft hand off algorithm. The fuzzy logic technique is applied for the three parameters (E_b/I_o, n_{OB},CH_{rm}) and the performance of the soft handoff algorithm has been analyzed. The effect of number of BS (n_{OB}), number of remaining channels of serving base stations (CHrm) and bit energy to noise plus interference ratio (E_b/I_0), have been evaluated for call blocking probability of on going calls and outage probability with traffic load.

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1. S. Qamar, M.Lal, S.C Sharma "A Dynamic Rate Based Bandwidth Borrowing Scheme for Multimedia Mobile Communication System" accepted for presentation in 10^{th} International conference on information analysis and systems 2004 and Cybernetic and Information Technology Systems and Applications (CITSA)-2004, 21-25 July 2004, Orlando, Florida, USA.
2. S. Qamar, M.Lal, S.C Sharma "Capacity Analysis of CDMA System" National Conference, Emerging Trends in Technology, 28 Feb. 2004, Computer Science Deptt. Rajkot, University, Rajkot.
3. S. Qamar, M. Lal, S.C Sharma "Diversity Technique For DS-CDMA Communication Network "Wireless Communication & Sensors Network Conference (WCSN-2005), 5-6 March 2005 at IIIT-Allahabad.
4. S. Qamar, M.Lal, S.C.Sharma, "Capacity Analysis Of MQAM/CDMA" IETE Conference Modern Trend in Electronics & Communication System, 6^{th} March 2005 at AMU, Aligarh.
5. S.Qamar, M.Lal, S.C.Sharma "Capacity of Multiple Access Scheme in Cellular Communication Network" accepted for presentation in IEEE, International Conference on Robotics, Vision, Information and Signal Processing, 20-23, July 2005, Malaysia.
6. S.Qamar, M.Lal, S.C Sharma "Performance of M-Ary CDMA Communication Network" IEE Mobility Conference, PP 62-63, 15-17 Nov 2005, China.

7. M.Lal, S.C.Sharma, S.Qamar "Selection Diversity for CDMA Communication Network" Computer Science & Technology Research Journal, Vol. IV, No. 4, 2006.
8. S. Qamar, S.C Sharma, M.Lal " Handoff Algorithms for mobile communication Network", Recent Advances in Process Control & Instrumentation Engineering Conference, 23-25 Feb 2006, Kurukshetra.
9. S.Qamar, S.C.Sharma, M.Lal "Effect of Interference and Control Error on Cellular Mobile Communication Networks." Journal of Annual Review of Communications , Volume 59, Dec.2006 , USA (Accepted)
10. S.C.Sharma, M.Lal, S.Qamar " capacity analysis of CDMA communication Network" Computer Science & Technology Research Journal Vol. V, N0.1, 2007 (Accepted)
11. S.Qamar, M.Lal and S.C. Sharma "Fuzzy technique on QoS parameter in CDMA Network" Computer Science of India Journal, New Delhi. (In process)

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List of Acronyms

ANN	Artificial Neural Network
AS	Active Set
AWGN	Additive white Gaussian Noise
BER	Bit Error Rate
BS	Base Station
BTS	Base Transceiver System
CDMA	Code Division Multiple Access
CDG	CDMA Development Group
CELP	Code Exited Linear Predictor
CDPD	Cellular Digital Packet Data
CCI	Co-Channel Interference
CS	Candidate Set
CCITT	Consultative Committee on International Telecommunication & Telegraph
dB	Decibels
DS	Direct Sequence
DSSS	Direct Sequence Spread Spectrum
EGC	Equal Gain Combining
EHDM	Extended Handoff Direction Message
FD	Full Duplex
FDMA	Frequency Division Multiple Access
FHSS	Frequency Hopping spread Spectrum
FTC	Fuzzy Threshold Control

FIS	Fuzzy Inference System
GHDM	General handoff Direction Message
GPS	Global Positioning System
GSM	Global System of Mobile Communications
GOS	Grade of service
GPRS	General Packet Radio Service
HHO	Hard Handoff
HCM	Handoff Completion Message
IF	Intermediate Frequency
LCR	Level Crossing System
LOS	Line of Sight
MPH	Minimum power Handoff
MRC	Maximum ratio Combining
MS	Mobile Station
MSC	Mobile Switching Center
MSS	Mobile Switching Subsystem
MTSO	Mobile Switching Center Office
NS	Neighbour Set
NLOS	Non Line of Sight
PACS	Personal access Communication system
PCS	Personal Communication System
PSK	Phase Shift Keying
PSMM	Pilot strength Measurement Message
QoS	Quality of Service

QPSK	Quadrature Phase Shift Keying
RS	Remaining Set
RSS	Received Signal Strength
SAT	Supervisory Auto Tone
SDC	Selection Diversity Combining
SNR	Signal To Noise Ratio
SHO	Soft Handoff
SIR	Signal To Noise Ratio
TDMA	Time Division Multiple Access
WCDMA	Wideband CDMA

CHAPTER 1

INTRODUCTION

1.1 Introduction

1.1.1 Code Division Multiple Access (CDMA) System

1.1.2 Capacity & Quality of Service

1.2 Problem in CDMA Network

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Chapter 1

Introduction

1.1 Introduction

The unabated growth in the use of wireless communication is continuing and new services are being introduced [119]. The goal in the design of cellular systems is to be able to handle as many calls as possible (this is called capacity in cellular terminology) in a given bandwidth with some reliability or quality of service [46, 110]. The Cellular communication systems divide a geographic region into cells where a mobile unit in each cell communicates with a base station [93]. There are several different ways to allow access to the channel. The wireless users access or share to a resource using multiple access technique. There are mainly three multiple access technique [73] namely Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). The FDMA is a technique whereby spectrum is divided up into frequencies and then assigned to users. The numbers of users are restricted by the number of available frequency channels [73]. The TDMA improves spectrum capacity by splitting each frequency into time slots. This allows each user to access the entire radio frequency channel for the short period of a call. Other users share this same frequency channel at different time slots. The numbers of users are

The CDMA is based on “spread” spectrum technology. It increases spectrum capacity by allowing all users to occupy all channels at the same time [93]. Transmissions are spread over the whole radio band, and each voice or data call is assigned a unique code to differentiate from the other calls carried over the same spectrum. The number of users can be increased as large as the number of available orthogonal codes. Capacity of CDMA network increases of 8 to 10 times that of an FDMA analog system and 4 to 5 times that of a GSM system [46]. The CDMA network uses Power control techniques are used to keep the transmitted power at the absolute minimum required to support a high call quality. The CDMA uses a technique known as soft handoff to receive signals from 3-5 adjacent cell sites at the same time, and combines the signals to eliminate the handoff muting as well as improving overall signal quality (by always selecting the best signal of the 3-5 that are received).The CDMA system uses Simplified system planning through the use of the same frequency in every sector of every cell. The CDMA system uses bandwidth on demand technique. This is due to variable rate voice coders which reduce the rate being transmitted when the speaker is not talking. This technique allows the channel to be packed more efficiently, resulting in additional capacity and allowing network to manage the Bandwidth. However, due to same spectrum available to each user CDMA system suffer from the interference. The interference increases as the number of users increases in the system and the performance of CDMA system decreases as the interference increases [93].

in the system and the performance of CDMA system decreases as the interference increases [93].

1.1.2Code Division Multiple Access (CDMA) System

The Code division multiple-access techniques allow many users to simultaneously access a given frequency allocation. User separation at the receiver is possible because each user spreads the modulated waveform over a wide bandwidth using unique spreading codes.

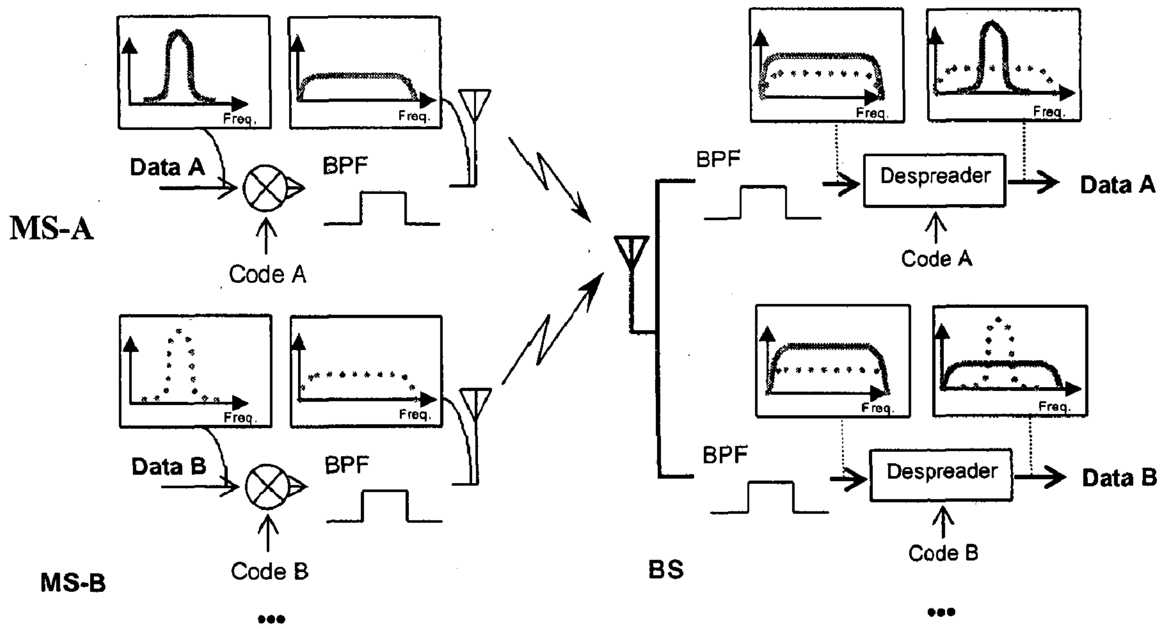

Figure 1.1: Signal Transmission of CDMA SYSTEM

unique high bandwidth pseudo-noise binary sequence. The resulting signal is then mixed up to a carrier frequency and transmitted. The receiver mixes down to base band and then re-multiplies with the binary {± 1} pseudo-noise sequence. This effectively (assuming perfect synchronization) removes the pseudo-noise signal and what remains (of the desired signal) is just the transmitted data waveform. After removing the pseudo-noise signal, a filter with bandwidth proportional to the data rate is applied to the signal. Because other users do not use completely orthogonal spreading codes, there is residual multiple-access interference present at the filter output. This interference limits the performance of CDMA system. Figure 1.2 shows the cell architecture of CDMA, identical radio resource are be used among all cells, because CDMA channels use same frequency simultaneously. Frequency allocation in CDMA is not necessary. So, CDMA cellular system is easy to be designed.

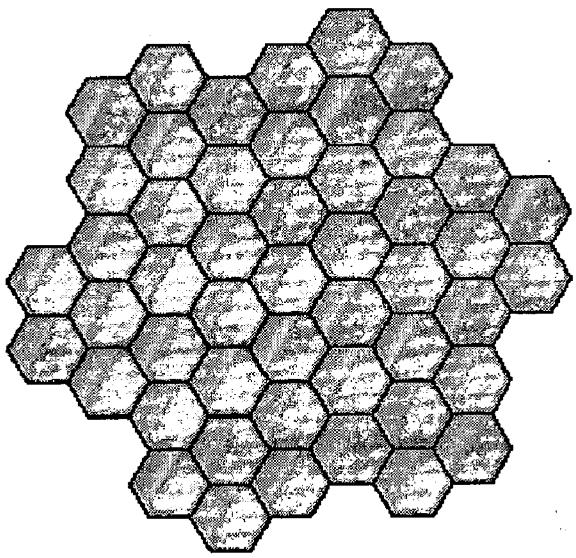

Figure: 1.2 Cell Architecture of CDMA Network

1.1.3 Capacity & Quality of Service

Capacity of a communication network is the maximum number of the subscribers that can be accommodated for a given quality of service parameters.The CDMA system is interference limited system since all the nearby cell uses same frequency spectrum. The capacity of the system decreases as the interference increases. Thus CDMA system capacity is interference limited. The quality of service parameters are signal to noise ratio, signal to interference ration, bit energy to noise ratio and bit error rate etc. These quality of service parameters become poorer due to increase in interference level. Also, quality of service parameters becomes poorer due to the problem of multipath phenomenon. Thus, multipath phenomenon affect the quality of service parameters and in turn capacity of the system.

1.2 Problem in CDMA Network

The CDMA Network have the following problems:

1. Interference Problem
2. Multipath Fading
3. Handoff Problem
4. Near far Problem

Interference of electromagnetic waves in communications can cause a serious problem. These electromagnetic waves combine vectorially to give a resultant signal which can be large or small depending upon whether the incoming or reflected waves combine destructively or constructively [141]. The destructive points known as nodes or minima and the constructive points known as maxima occur repeatedly in a regular standing wave pattern along the transmission line. In nodes the signals are much weaker than in maxima. This fundamental phenomenon also occurs in a CDMA mobile radio communications network where the mobile stations may change their location freely from one location to another. Once the radio wave is launched from an antenna we can not ensure that it will always reach the receiver antenna directly. Large obstructions such as hills or mountains may weaken the radio wave from a mobile station or even cause a complete loss of the signal. This phenomenon is known as slow fading [92,96]. Another phenomenon is that the radio wave reaches the receiver antenna from many directions with different time delay after experiencing reflection, refraction or scattering. These multipath radio waves will also vectorially combine and produce substantial amplitude fluctuations that create an "irregular" standing wave or the multipath fast fading signal. In such conditions , the nodes or deep fades, as they are referred to in mobile communications, can be 10 dB or more below the rms value of the fading envelope. The method for mitigating the multipath fading problem is by means of diversity techniques [82,130,23,45,115,116,157,2,92]. In a diversity reception system several similar copies of the transmitted signals are resolved from the multipath-fading signal and by properly combining them we may reduce the performance degradation of the system. The advantage of this method is that there is no requirement for either increasing the transmitted power or the bandwidth [141,132]. The handoff is a process of transferring a mobile station from one base station or channel to another. The handoff procedure should be smooth, fast and without breaking of the old connection. The soft handoff is the make before break strategy. The handoff procedure should maintain the bit error rate, signal to noise ratio.

The CDMA has problem the mobile radio environment called the "near-far problem." It is always assumed that all the stations transmitted constant power. In the mobile radio environment some users may be located near the base station, others may be located far away. The propagation path loss difference between those extreme users can be many tens of dB. The mobile user near the base station receive more energy than the mobile user which is far away from the base station. To achieve the same signal to interference ratio at the both unit, the signal power for the far mobile should be high. This high power acts like an interference for the near user.

Our concern in this thesis is with methodological issues to find the total number of simultaneous users and quality of service parameters that can obtain useful gain through a diversity connection in CDMA mobile radio communication system in a multipath fading environment. The total number of simultaneous users in the system is defined as the system capacity in this Thesis.

1.3.1 Multipath and Diversity in CDMA:

Because there are obstacles and reflectors in the wireless propagation channel, the transmitted signal arrivals at the receiver from various directions over a multiplicity of paths. Such a phenomenon is called multipath. It is an unpredictable set of reflections and/or direct waves each with its own degree of attenuation and delay [31].The multipath will cause amplitude and phase fluctuations, and time delay in the received signals. When the waves of multipath signals are out of phase, reduction of the signal strength at the receiver can occur. One such type of reduction is called the multipath fading; the phenomenon is known as "Rayleigh fading" or "fast fading. A diversity scheme is a method that is used to develop information from several signals transmitted over independent fading paths. This means that the diversity method requires that a number of transmission paths be available, all carrying the same message but having independent fading statistics. The mean signal strengths of the paths should also be approximately the same. The basic requirement of the independent fading is received signals are uncorrelated. Therefore, the success of diversity schemes depends on the degree to which the signals on the different diversity branches are uncorrelated [23]. Proper combining the multiple signals will greatly reduce severity of multipath fading and improve reliability of transmission [45,115,70,90, 16,157,1,145,126,91,2,24]. Because deep fades seldom occur simultaneously during the same time intervals on two or more paths. The simplest combining scheme is selection combining, which is based on the principle of selecting the best signal (the largest energy or SNR) among all of the signals received from different branches of the CDMA communication receiver [71,157].

1.4 Handoff in CDMA

In cellular telecommunications, the term handoff refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another[49]. The most basic form of handoff is that used in GSM and analog cellular networks, where a phone call in progress is redirected from one cell site and its transmit/receive frequency pair to another base station (or sector within the same cell) using a different frequency pair without interrupting the call[49,42]. As the phone can be connected to only one base station at a time and therefore needs to drop the radio link for a brief period of time before being connected to a different, stronger transmitter, this is referred to as a hard handoff. This type of handoff is described as "break before make" (referring to the radio link)[49,147].

The CDMA systems the phone can be connected to several cell sites simultaneously, combining the signalling from nearby transmitters into one signal using a rake receiver [128,167]. Due to the properties of the CDMA signaling scheme, it is possible for a CDMA subscriber station to simultaneously receive signals from two or more radio base stations that are transmitting the same bit stream on the same channel.

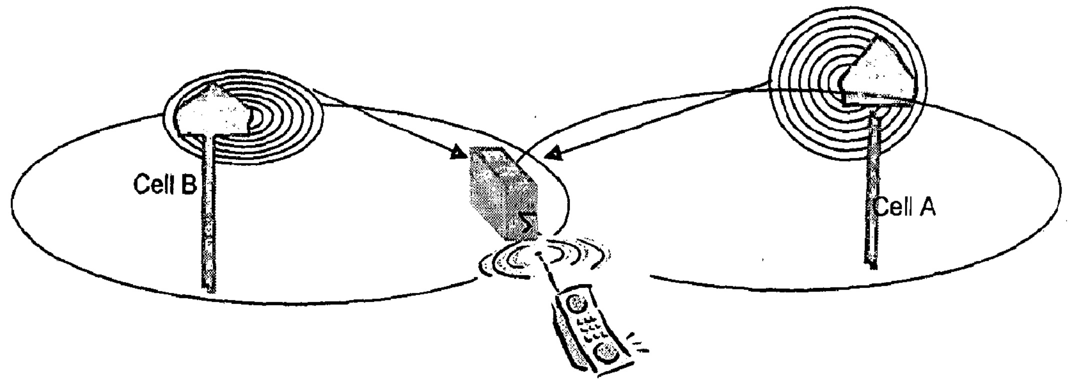

Figure 1.3 Soft Handoff: break (old cell A) after connect (new Cell B cell B)

If the signal power from two or more radio base stations is nearly the same, the subscriber station receiver can combine the received signals in such a way that the bit stream is decoded much more reliably than if only one base station were transmitting to the subscriber station. If any one of these signals fades significantly, there will be a relatively high probability of having adequate signal strength from one of the other radio base stations [122].On the "reverse" (mobile-phone-to-cell-site) link, all the cell site sectors that are actively supporting a call in soft handover send the bit stream that they receive back to the Base Station Controller (BSC), along with information about the quality of the received bits. The BSC examines the quality of all these bit streams and dynamically chooses the bit stream with the highest quality. Again, if the signal degrades rapidly, the chance is still good that a strong signal will be available at one of the other cell sectors that is supporting the call in soft handover [54].

1.5 OBJECTIVE OF THE PRESENT STUDY /RESEARCH WORK:

The objective of the present research work is to study the performance of various diversity combining technique in CDMA system that appeared in the literature and to modify the possibilities of enhancements for the existing model and further to apply fuzzy on diversity and handoff in CDMA system.

To fulfill the above objectives, the analysis is carried out as follows:

1. To analyze the probability of bit error rate for combined effect of antenna diversity and spread spectrum diversity
2. To study bit error rate performance for the switched diversity for the optimum switching threshold using fuzzy technique
3. To evaluate the performance of the soft handoff provided by the macro diversity due to two base stations simultaneously involved in communication.
4. To apply fuzzy logic technique to enhance the performance of the soft handoff algorithm.

1.6 Organization of the thesis

This thesis consists of seven chapters. The organization of the thesis is as follows:

Chapter 1: presents the introduction and significance of the topic. Chapter 2 provides a brief review of the diversity, soft handoff (macro diversity) and literature survey. Chapter 3 describes the Bit error rate performance antenna diversity with spread spectrum diversity. In Chapter 4, the switched diversity is described and the closed form expression is obtained, the optimum switching threshold is derived and the fuzzy logic technique is applied on the switching threshold to optimize the bit error rate performance. In Chapter 5, the macro diversity due to two base station involved in communication with the mobile during soft handoff is considered, the SIR is combined from the two Bs's proposed and the number of user in the system has been calculated. Chapter 6 presents fuzzy technique to a soft handoff algorithm for CDMA communication network. Chapter 7 presents the concluding remarks and future prospects.

Chapter 2

Diversity and Handoff Technique

Chapter 2

Diversity and Handoff Technique

2.1 Introduction

The diversity combining is the technique applied to combine the multiple received signals of a diversity reception device into a single improved signal. The signals are combined at the receiver by using diversity combiner.

The diversity is a well known technique for improving performance in CDMA mobile communications Network and soft handoff is a technique to improve Quality of service in soft handoff region using macro diversity combining technique. Diversity paths carry the same information but experience independent fading. By appropriately combining these paths, the effect of excessively deep fades in the received signal can be reduced. The diversity paths can be obtained in two ways. Thus, there are two types of diversity.

(i) External diversity- by deliberately generating them using techniques such as space, time or frequency diversity. This is known as external diversity.

(ii) Internal Diversity- by exploiting the multipath nature of the channel. This is known as inherent or internal diversity.

2.2 Diversity paths

A mobile station (MS) may experience a significant loss of the transmitted signal if there is a large obstruction (such as hill or building), which shadows its communication link. This type of fading is known as long-term fading. To combat this type of fading, macroscopic diversity is used. A simple method is to use several base stations (BS) located in several strategic positions to ensure that there at least is one clear communication link between the MS and the BS at any time. More often occurring in a mobile radio communication environment is the phenomenon called short term or fast fading. Methods for counteracting this fading type are called microscopic diversity. This term is used because the diversity paths in the fast fading environment are separated by intervals *equivalent to a delay varying from a fraction to several wavelengths. In order to* effectively use either macroscopic or microscopic diversity in combating slow or fast fading we need several uncorrelated diversity paths. There are three different techniques for generating the uncorrelated diversity paths that will be briefly discussed in this section.

(a) Space Diversity

This technique involves transmitting and/or receiving the same information using several well-separated antennas. It is widely used in a variety of microwave communication systems. In space diversity the antennas can be separated vertically or horizontally either in the base station or in the mobile station. [82,71]

(b) Frequency Diversity

The same information is transmitted using two or more carrier frequencies in frequency diversity. This method is economical in terms of antennas but requires more bandwidth. In order to obtain frequency diversity paths that fade independently, the separation between the carrier frequencies should be greater than several times the coherence bandwidth [4].

The coherence bandwidth (B_c) can be defined [4], as the frequency separation for which the magnitude of the normalized complex correlation coefficient between the signals (diversity paths) drops below a certain value. Yacoub [83] assumed this correlation value as 0.5. The coherence bandwidth is inversely proportional to the multipath delay spread of the channel.

(c) Time Diversity

Different time slots are used to transmit the same information in time diversity. In the case of sending repetitive data through the multipath channel the inter transmission time is an important factor in ensuring the received signals experience independent fading. This time interval (τ_s) should be greater than the reciprocal of the baseband fade rate [4] or in other words the time interval must exceed the coherence time (τ_c) of the channel [166]. Note that the coherence time is not directly related to the coherence bandwidth but inversely proportional to the doppler shift (f_d).

$$\tau_s \geq 1/(2\pi f_d) \qquad (2.1)$$

where $f_d = v/\lambda$, where v is the speed of the MS and λ is the wavelength. For example, in an environment where a MS moving with a speed of 60 km/h and operating at a carrier frequency of 900 MHz, a time interval of 10 ms between the independent diversity paths is required.

2.3 Internal diversity and resolvable paths

In a sufficiently wideband transmission system like CDMA system, a multipath signal can be viewed as creating a series of diversity paths. Resolving the number of paths and their parameters will be discussed in this section. This diversity technique is called multipath diversity in some references [120,121]. The inherent diversity paths in the multipath fading envelope are called internal diversity paths. The number of resolvable paths, L, is related to the coherence bandwidth, Bc, and also to the bandwidth of the signal. The relationship between the multipath delay spread ΔT and the transmitted pulse duration, Tc, defines the behaviour of the channel. If $\Delta T \geq Tc$, the channel is a frequency selective channel while if $\Delta T \leq Tc$ the channel is a frequency nonselective channel. In a frequency selective channel there can be several (say L) trains of pulses with duration T_c in the multipath delay spread of the channel. In other words, there will be L diversity paths. Thus the maximum number of resolvable independent diversity paths that can be obtained is as in [4]

$$L \leq (\Delta T / T_c) + 1 \tag{2.2}$$

The Rake receiver is capable of extracting diversity paths received from the multipath propagation environment. Typical values of mean delay spread can be several μs in urban areas and fraction of μs in suburban areas [91]. The

Qualcomm CDMA system uses a chip rate of 1.2288 MHz or Tc = 0.81μs. In an urban area with delay spread of 5 μs, the Rake receiver is capable of resolving up to 6 diversity paths. However this process requires the amplitude and the phase of the diversity paths to be estimated on a continuous basis. In practice, relatively good estimates can be obtained if the channel fading is sufficiently slow or in other words the coherence time of the channel, τ_c is much greater than the data symbol period, Ts i.e. $(\tau_c / Ts) \geq 100$ [118]. From equation (2.2) we may conclude that the longer the time delay spread of the channel, the more diversity paths can be obtained. It is seen that the diversity combiner performance will not improve much for L > 3. On the other hand the longer the value of ΔT, the longer the required waiting time before sending the next pulse if intersymbol interference is to be avoided. This causes the signaling rate to be reduced.

2.4 Diversity combining Methods

The diversity combiner combines the signals in constructive manners to those signals, which are obtained through diversity paths. There are two main issues in reviewing the properties of alternative diversity combiners. The first is related to where the combining process takes place in the system and the second is how to combine the diversity paths. We will briefly review where the combining process takes place before focusing on the combining method. (1) Predetection and (2) Post detection.

There are two locations where diversity paths can be combined in a diversity receiver. If the combining process occurs after the Intermediate Frequency (IF) stage and before the detection process then it is called a predetection combiner.

On the other hand, in the post detection combiner, each diversity path is combined in the base band stage. The main differences between these two basic types of diversity combiners are described [117] in terms of the detector used in the system and the extra circuitry required, such as a co phasing circuit. If a nonlinear detector (e.g. a square-law detector) is used, the predetection combiner performs better than the post detection combiner. Parson[117] stated that in case where two identical paths are combined, predetection may have a 3 dB signal to noise ratio gain over post detection. On the other hand, predetection requires complicated co phasing circuitry before combining all the paths. The co phasing circuit is not necessary in the post detection method since combining occurs at base band.

There are two main types of diversity combiner, the switch combiner and the gain combiner. Examples of the switch combiner are the scan diversity combiner and the selection diversity combiner. Examples of the gain combiner are the equal gain combiner and the maximal ratio combiner.

A linear combiner is most often used in practical applications. The output of a linear combiner for L diversity paths can be expressed as-

$$r(t)=\sum_{K=1}^{L}a_k r_k(t) \qquad (2.3)$$

Where a_k is the weight assigned to the signal component in the k-th diversity path respectively. The choice of a_k, as seen later will define the type of combiner. To compare the signal to noise ratio and bit error rate performance of three commonly used diversity combiners (selection, equal gain and maximal ratio combiner) several assumptions are made, we summaries some assumptions as in [23] for the diversity combiner inputs.

- The noise in each path is independent of the signal, and additive.
- The signals are locally coherent. This implies that the fade rate is very slow in Comparison to the lowest modulation frequency present in the signal.
- The noise components are locally incoherent (i.e. uncorrelated) with zero
- means and the local mean square values (noise powers) are slowly varying or constant.
- The local rms values of the signals are statistically independent.

Table 2.1 Comparison of Diversity Schemes

Type of diversity	Properties	Mathematical model	Remark
Selection diversity Combining (SDC)	The diversity path having the strongest signal is selected	SNR is maximized by single chosen path, other path gain is zero.	Probabilty of error decreases with SNR, incremental benefit decreases as the number of paths increases
Equal gain Combining (EGC)	All signal are equally weighted and combined combined	SNR is maximized by combining all the path signal with equal weights	The Probability of error of EGC performs better than the SDC and is only about 1 dB worse than the MRC
Maximum ratio Combining (MRC)	Signals weights are unequal, SNR is maximized	SNR is maximized by combining all the path signal with unequal weights	The SNR at the output of MRC is better than can be achieved with any other linear combiner, Probabilty of error performance is best.

2.6 Concept of Cellular Handoff

The handoff is a process of transferring a mobile station from one base station or channel to another. The channel change due to handoff occurs through a time slot for time division multiple access (TDMA), frequency band for frequency division multiple access (FDMA), and codeword for code division multiple access (CDMA) systems [98]. Handoff may be hard or soft. Hard handoff (HHO) is "break before make," meaning that the connection to the old BS is broken before a connection to the candidate BS is made. The hard hand off (HHO) occurs when handoff is made between disjointed radio systems, different frequency assignments, or different air interface characteristics or technologies [147]. Soft handoff (SHO) is "make before break," meaning that the connection to the old BS is not broken until a connection to the new BS is made. In fact, more than one BS are normally connected simultaneously to the MS. For example, in Figure 2.7, both the BSs will be connected to the MS in the handoff region.

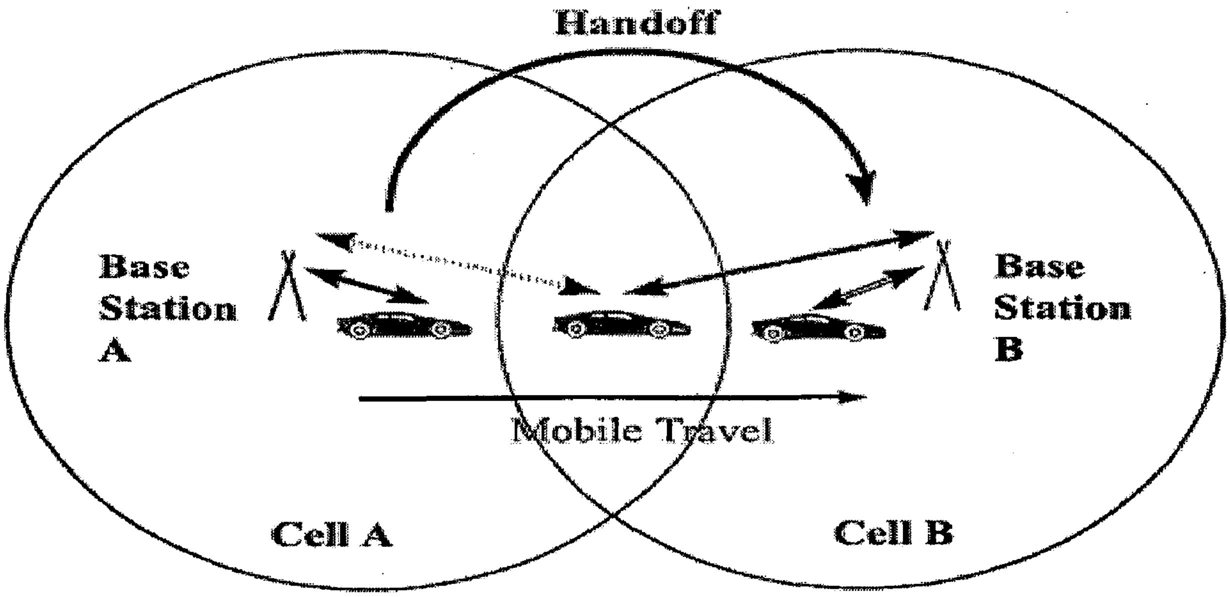

Figure 2.7 Handoff Procedure in Cellular System

2.6.1 Terminology and Parameters of Handoff

Some of the terminology used in cellular communications is explained[159].

Mobile Station (MS): The mobile station is intended for use while in motion at an unspecified location.

Base-Station (BS): The base station is a fixed station used for radio communication with MSs.

Mobile Switching Center (MSC): The mobile switching center coordinates the routing of calls in a large service area. It is also referred to as the Mobile Telephone Switching Office (MTSO).

Forward Channel: The forward channel is the radio channel used for the transmission of information from the base station to the mobile station. It is also known as the downlink.

Reverse Channel: The reverse channel is the radio channel used for the transmission of information from the mobile station to the base station. It is also known as the uplink.

Co channel Interference (CCI). The co channel interference is caused when the desired signal and another signal in some remote cell are using the same frequency or channel. The following phases are involved in the planning of cellular communications.

- Assessment of traffic density
- Selection of best BS sites to cover the required area
- Frequency allocation
- Determination of cell sizes and capacity

- Decisions about omni directional or sectored cells and antenna directions
- Choice of power control parameters
- Selection of handoff parameters.

Figure 2.7 shows a simple handoff scenario in which an MS travels from BS A to BS B. Initially, the MS is connected to BS A. The overlap between the two cells is the handoff region in which the mobile may be connected to either BS A or BS B. At a certain time during the travel, the mobile is handed off from BS A to BS B. When the MS is close to BS B, it remains connected to BS B. The overall handoff procedure can be thought of as having two distinct phases[160]. The initiation phase (in which the decision about handoff is made) and the execution phase (in which either a new channel is assigned to the MS or the call is forced to terminate). Handoff algorithms normally carry out the first phase. Handoff may be caused by factors related to radio link, network management, or service options[98,159].

Radio Link Related Causes: Radio link related causes reflect the quality perceived by users. Some of the major variables affecting the service quality are received signal strength (RSS), signal-to-interference ratio (SIR), and system related constraints. Insufficient RSS and SIR reduce the service quality. Moreover, if certain system constraints are not met, service quality is adversely affected. Handoff is required in the following situations due to reduced RSS [159]: (i) when the MS approaches the cell boundary (the RSS drops below a threshold) and (ii) when the MS is inside the signal strength holes in a cell (the signal is too weak to be detected easily). SIR drops, as CCI increases and handoff are required. Bit error rate (BER) can be used to estimate SIR.

2.7.1 Desirable Features of Handoff

An efficient handoff algorithm can achieve many desirable features by trading different operating characteristics. Figure 2.8 summarizes the major desirable features of handoff algorithms, and several desirable features of handoff algorithms mentioned in the literature are described below [150,147,105,151,152,110,160]

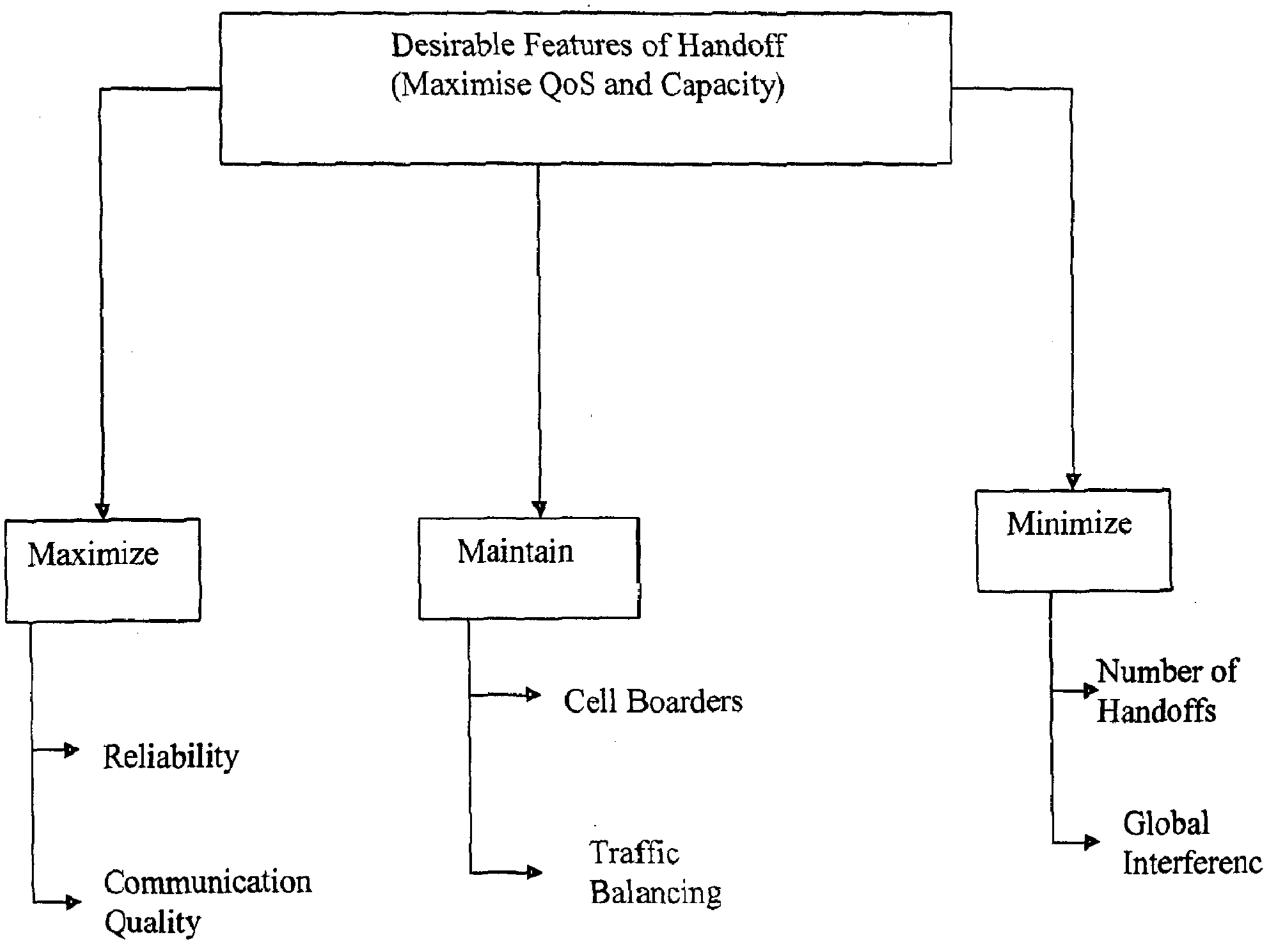

Figure 2.8 Features of Handoff

Handoff should be fast so that the user does not experience service degradation or interruption. Service degradation may be due to a continuous reduction in signal strength or an increase in CCI. Service interruption may be due to a break before make" approach of HHO. Note that the delay in the execution of a handoff algorithm adds to the network delay at the Mobile Switching Center (MSC) or Mobile Telephone Switching Office (MTSO). Fast handoff also reduces CCI since it prevents the MS from going too far into the new cell.

- Handoff should be reliable
- Handoff should be successful
- The number of handoffs should be minimized

2.7.2 Handoff Criteria

The different handoff criteria are proposed in literature mainly include signal strength, SIR, distance, transmit power, traffic, call and handoff statistics, and velocity. Received Signal Strength (RSS). This criterion is simple, direct, and widely used. Many systems are interference limited, meaning that signal strength adequately indicates the signal quality, and this is the motivation behind signal strength based decision. Moreover, there is a close relation between the RSS and the distance between the BS and the MS. The lack of consideration of CCI is a disadvantage of this criterion. CCI is more important in micro cells (with a cell radius less than 1 km) than in macro cells since microcellular systems are interference limited and macro cells are noise-limited, (with cell radius exceeding

35 km in rural areas). Moreover, several factors (e.g., topographical changes, shadowing due to buildings, and multipath fading) can cause the actual coverage area to be quite different from the intended coverage area. The RSS criterion can also lead to excessive number of handoffs.

Signal-to-Interference Ratio (SIR) An advantage of using SIR or Carrier to interference ratio (C/I) as a criterion is that SIR is a parameter common to voice quality, system capacity and dropped call rate. BER is often used to estimate SIR. When actual received (C/I) is lower than the designed (C/I), voice quality becomes poor, and the rate of dropped calls increases. SIR also determines the reuse distance. Unfortunately, CIR may oscillate due to propagation conditions and may cause the ping-pong effect (in which the MS repeatedly switches between the adjacent BSs). Another disadvantage is that even though BER is a good indicator of link quality, bad link quality may be experienced near the serving BS, and handoff may not be desirable in such situations [47]. In an interference-limited environment, deterioration in BER does not necessarily imply the need for an intercell handoff; an intracell handoff may be sufficient[133]. Two methods for estimating raw channel BER over a Rayleigh fading channel are presented in [84].

Distance This criterion can help preserve planned cell boundary. The distance can be estimated based on signal strength measurements [99], delay between the signals received from different BSs [52], etc. Distance measurement can improve the handoff performance [134]. If handoff occurs at the midway between two BSs, it distributes the channel utilization evenly [166]. The distance criterion may be useful for a macro cellular system, but it is prohibitive in a microcellular system since the precision of the distance measurement decreases with smaller cell sizes [47]. Theoretical analysis in [5] does not consider distance criterion better than others. The determination of cell boundaries can avoid unnecessary handoffs. In the German cellular system (C/I) and other data (such as signal strength, phase jitter, and the phase difference of the received digital signals) are measured and processed to detect the cell boundaries[5].

Transmit Power Transmit power can be used as a handoff criterion to reduce the power requirement, reduce interference, and increase battery life.

Traffic Traffic level as a handoff criterion can balance traffic in adjacent cells [153]. S.Rappaport [135] developed an analytical model for traffic performance analysis of a system. Statistics of dwell times are important for teletraffic performance evaluation [159].

Call and Handoff Statistics Statistics such as total time spent in the cell by a call and arrival time of a call in a cell can also be used as handoff criteria [105]. Elapsed time since last handoff is also a useful criterion since it can reduce the number of handoffs [159].

Velocity. Velocity is an important handoff criterion, especially for overlay systems and velocity adaptive algorithms. Several algorithms use an estimate of velocity to modify handoff parameters. J.M Holtzman et al [74] developed a method to adaptively change the averaging interval in a handoff algorithm for both small and large cells is presented. The method is based on the estimation of mobile velocity through maximum Doppler frequency f_D. A method for estimating

f_D from squared deviations of the signal envelope, both in Rayleigh fading and Rician fading environments has also discussed in this literature.

2.8 Conventional Handoff Algorithms

The various conventional handoff algorithm reported in literature are described below.

2.8.1 Signal Strength Based Algorithms

The signal strength based algorithm continuously measures the signal strength and the handoff decision depends on the value of signal strength.

There are several variations of signal strength based algorithms, including relative signal strength algorithms [142], absolute signal strength algorithms, and combined absolute and relative signal strength algorithms.

2.8.2 Relative Signal Strength Algorithms: According to the relative signal strength criterion [142], the BS that receives the strongest signal from the MS is connected to the MS. The advantage of this algorithm is its ability to connect the MS with the strongest BS. However, the disadvantage is the excessive handoffs due to shadow fading variations associated with the signal strength. In many of the existing systems, measurements for candidate BSs are not performed if field strength for the existing BS exceeds a prescribed threshold. The advantage of this approach is that the reduced processing load. However, the disadvantage is the MS's retained connection to the current BS even if it passes the planned cell boundary as long as the signal strength is above the threshold.

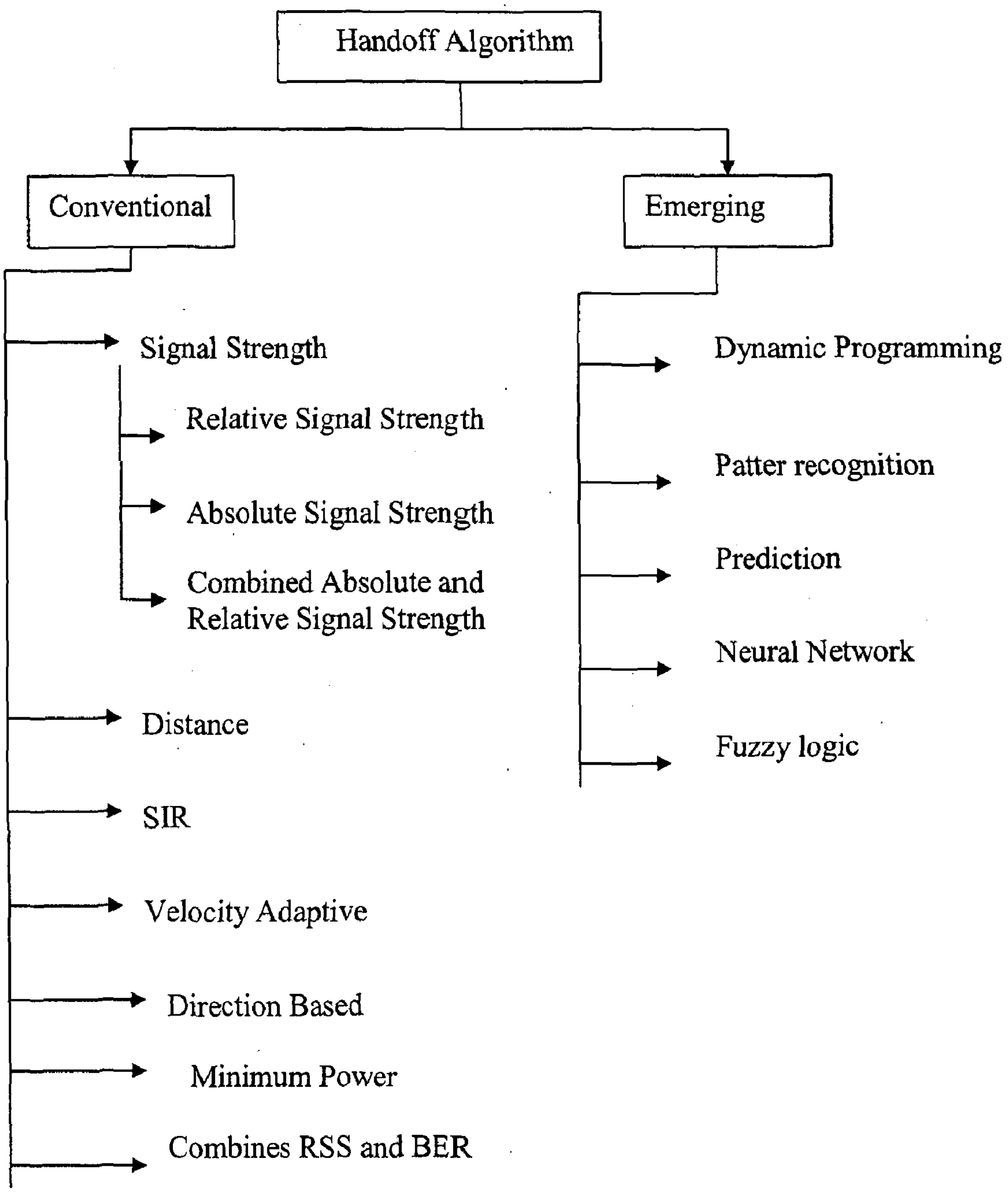

Figure2.9 Classification of Handoff Algorithms

A variation of this basic relative signal strength algorithm incorporates hysteresis. For such an algorithm, a handoff is made if the RSS from another BS exceeds the RSS from the current BS by an amount of hysteresis. The North American Personal Access Communication Systems (PACS) personal communication services (PCS) standard combines hysteresis with a dwell timer [48]. Hysteresis reduces the number of unnecessary handoffs but can increase dropouts since it can also prevent necessary handoffs by introducing a delay in handoff [50]. A necessary balance between the number of handoffs and delay in handoff needs to be achieved by appropriate hysteresis and signal strength averaging. G.Corazza et al [49] described a software simulator that allows the design of the number of samples to be averaged and of the hysteresis margin. Rectangular and exponential averaging windows are considered. The averaging should consider the MS speed and shadow fading. The shadow fading is characterized by a Gaussian distribution with zero mean and certain standard deviation (which depends on the environment). A scheme for estimating the shadow fading standard deviation based on squared deviations of the RSS at the MS is given in [6]. It is shown by R.Vijayan[127] that the optimum handoff algorithm parameters are very sensitive to shadow fading standard deviation. To achieve robustness, more averaging and less hysteresis are required. However, to detect sudden changes in signal strength (e.g., due to street corner effect), less averaging and more hysteresis are required. To resolve this conflict, shadow fading deviation is estimated and used [74]. If the averaging interval is too short, fading fluctuates greatly. If it is too long, handoff is delayed. Thus, it is important to have an adaptive averaging interval. The time varying intensity of Rayleigh fading depends on the maximum Doppler frequency proportional to the mobile velocity. Similarly, shadow fading depends on the velocity due to its dependence on distance. Thus, an averaging interval can be determined based on maximum Doppler frequency. J.M Holtzman [74] determines the adaptive averaging interval through estimating maximum Doppler frequency by exploiting Rayleigh fading fluctuations.

P.Dassanayake [120,121] characterize the variance of signal strength of the cell propagation environment and present its effect on handoff parameters such as signal averaging time and hysteresis. The simulation results based on GSM indicate that dynamic adjustment of propagation dependent handoff parameters could enhance the handoff performance.

Typical threshold values are -100 dBm for a noise-limited system and -95 dBm for an interference-limited system [159]. Better handoff initiation can be obtained by varying the threshold [159]. The threshold level should be varied according to the path loss slope L of the RSS and the level crossing rate (LCR) of the RSS. If the slope L is high or LCR is high, the MS is quickly moving away from the BS, and, hence, handoff should be made fast (i.e., the handoff initiation threshold should be made higher in magnitude). If the slope L or LCR is low, the MS is moving slowly. So, handoff can be slow, the handoff initiation threshold can be made comparatively smaller. Thus, the mobile velocity and path-loss slope L can be used to determine the handoff initiation threshold dynamically such that the number of unnecessary handoffs is minimized and necessary handoffs are completed successfully.

This algorithm has a serious disadvantage. When a threshold level is set based on the RSS, the following situations pose a problem [159] (i) when RSS is high due to high interference, the handoff will not take place, although, ideally, handoff is desirable to avoid interference (ii) when RSS is low, handoff takes place even if voice quality is good, although, ideally, such a handoff is not required and some systems use supervisory audio tone (SAT) information with the RSS to avoid handoff.

2.8.2 Distance Based Algorithms

This algorithm connects the MS to the nearest BS. The relative distance measurement is obtained by comparing propagation delay times. This criterion allows handoff at the planned cell boundaries, giving better spectrum efficiency compared to the signal strength criterion in [142]. German cellular system C450 uses this handoff criterion in [53]. However, it is difficult to plan cell boundaries in a microcellular system due to complex propagation characteristics. Thus, the advantage of distance criterion over signal strength criterion begins to disappear for smaller cells due to inaccuracies in distance measurements. A relative signal strength based algorithm gives less interference probability compared to a relative distance based algorithm. In particular, when an LOS path exists between the current and distant BS and the MS, the current BS gives stronger signal strength compared to the nearer NLOS BS. In such cases, the relative signal strength criterion can avoid interference and the relative distance criterion experiences more interference.

2.8.3 SIR Based Algorithms

The signal to interference ratio (SIR) at the cell boundary should be relatively high (e.g., 18 dB for AMPS and 12 dB for GSM) for toll quality voice. However, a lower SIR may be used for capacity reasons since co channel distance and cluster size (i.e., the number of cells per cluster) are small for lower SIR and channels can be reused more frequently in a given geographical region [159]. SIR is a measure of communication quality. This algorithm makes a handoff when the current BS's SIR drops below a threshold and another BS can provide sufficient SIR. Hysteresis can be incorporated in the algorithm. The lower SIR may be due to high interference or low carrier power. In either case, handoff is desirable when SIR is low. However, SIR-based handoff algorithms prevent handoffs near nominal cell boundaries and cause cell dragging and high transmit power requirements [32]. C.N.Chuah [33] has suggested an uplink SIR-based algorithm for a power-controlled system. Each user tries to achieve a target SIR_t. Handoff is made when the user's SIR drops below a threshold SIR_{ho}, which is normally less than SIR_t.

2.8.4 Velocity Adaptive Algorithms

Handoff requests from fast moving vehicles must be processed quickly. A handoff algorithm with short temporal averaging windows can be used to tackle fast users. However, the concept of a "short" averaging window is relative to the mobile speed. Thus, optimal handoff performance will be obtained only at one speed if the length of the averaging window is kept constant. A velocity adaptive handoff algorithm provides good performance for MSs with different velocities by adjusting the effective length of the averaging window [100]. A velocity adaptive handoff algorithm can serve as an alternative to the umbrella cell approach to tackle high speed users if low network delay can be achieved, which can lead to savings in the infrastructure. One of the velocity estimation techniques uses level crossing rate (LCR) of the RSS in which the threshold level should be set as the average value of the Rayleigh distribution of the RSS by K.Kawabata [85], requiring special equipment to detect the propagation dependent average receiver power. K.Kawabata [85] discussed a method of velocity estimation in a Rayleigh fading channel based on velocity's proportionality to the Doppler frequency. The velocity estimation technique exploits diversity reception. If the MS is already using selection diversity, special equipment is not required for this method M.Austin[100] described the velocity adaptive handoff algorithms for microcellular systems are characterized.

2.8.5 Direction Biased Algorithms

In an NLOS handoff, the MS experiences the corner effect. Hence, if the MS moves fast and is not handed off quickly enough to another BS, the call will be dropped. Connecting the fast moving vehicles to an umbrella cell is one solution, and using better handoff algorithms is another solution. A direction biased handoff algorithm represents such an alternative solution [101]. Direction biasing improves cell membership properties and handoff performance in LOS and

NLOS scenarios in a multi-cell environment. A handoff algorithm is said to possess good cell membership properties if the probability that the MS is assigned to the closest BS is close to one throughout the call duration [101]. Improvement in cell memberships leads to fewer handoffs and reduced interference. The basic idea behind this algorithm is that handoffs to the BSs towards which the MS is moving are encouraged, while handoffs to the BSs from which the MS is receding are discouraged. This algorithm reduces the probability of dropped calls for hard handoffs (e.g., for TDMA systems). The algorithm also reduces the time a user needs to be connected to more than one base station for soft handoffs (e.g., for CDMA systems), allowing more potential users per cell.

A variation of the basic direction-biased algorithm is the pre-selection direction biased algorithm [101]. If the best BS is a receding one and has a quality only slightly better than the second best BS which is being approached, the handoff should be made to the second best BS because it is more likely to improve its chances of being selected. This provides a fast handoff algorithm with good cell membership properties without the undesirable effects associated with large hysteresis. Another variation of the basic direction-biased algorithm is a fuzzy logic based direction-biased algorithm [101].

2.8.6 Minimum Power Algorithms

A minimum power handoff (MPH) algorithm that minimizes the uplink transmit power by searching for a suitable combination of a BS and a channel is suggested in [32] by C.N.Chuah . This algorithm reduces call dropping but increases the number of unnecessary handoffs. To avoid a high number of handoffs, the use of a timer is suggested. First, the channel that gives minimum interference at each BS is found. Then, the BS that has a minimum power channel is determined.

W.Mende [160] used a power budget criterion to ensure that the MS is always assigned to the cell with the lowest path loss, even if the thresholds for signal strength or signal quality have not been reached. This criterion results in the lowest transmit power and a reduced probability of CCI.

2.8.7 RSS and BER Based Algorithms

An algorithm based on both RSS and BER is described by S.Chia [134]. For RSS, a threshold is used for the current BS, and a hysteresis window is used for the target BS. For BER, a separate threshold is defined. The target BS can be either included or excluded from the handoff decision process. The latter scheme is used in GSM in which the mobile does not know the signal quality of the target BS. In principle, it is possible to measure BER of the control channel of the target BS. Three parameters considered in the simulations in [134] are RSS threshold, BER threshold, and RSS hysteresis window size. The effects of these parameters on handoff probability are discussed in [134]. In general, a low threshold value reduces the handoff request probability. The best threshold value is the average signal level at the mid-point between two BSs. However, due to the propagation environment, this threshold must be estimated for each base site. An RSS hysteresis delays handoff significantly. The higher the BER threshold, the earlier the handoff request. Moreover, if the BER threshold of target BS is used, handoff request is delayed. The handoff request probability differs significantly with location (or BS sites), showing that propagation characteristics are highly dependent on local terrain features and environment. From experimental results, it was found that the signal level and BER profiles varied significantly. RSS gives a direct indication of the received energy at the MS, while BER gives an indication of CCI and transmission quality [134].

2.9 Emerging Handoff Algorithms

The various emerging handoff algorithm reported in literature are discussed. Some of them are briefly described below.

2.9.1 Dynamic Programming Based Handoff Algorithms

Dynamic programming allows a systematic approach to optimization. However, it is usually model dependent (particularly the propagation model) and requires the estimation of some parameters and handoff criteria, such as signal strengths. So far, dynamic programming has been applied to very simplified handoff scenarios only. Handoff is viewed as a reward/cost optimization problem in [102]. RSS samples at the MS are modeled as stochastic processes. The reward is a function of several characteristics (e.g., signal strength, CIR, channel fading, shadowing, propagation loss, power control strategies, traffic distribution, cell loading profiles, and channel assignment). Handoffs are modeled as switching penalties that are based on resources needed for a successful handoff. Dynamic programming is used to derive properties of optimal policies for handoff. Simulation results show this algorithm to be better than relative signal strength based algorithm. Kelly et al [113] views signal strength based handoff as an optimization problem to obtain a tradeoff between the expected number of handoffs and number of service failures, events that occur when the signal strength drops below a level required for an acceptable service to the user. An optimal solution is derived based on dynamic programming and is used for comparison with other solutions. The handoff problem is defined as a definite horizon dynamic programming problem, and an optimal solution is obtained through a set of recursive equations. This optimal solution is complex and requires a priori knowledge of the mobile trajectory. A locally optimal (or greedy) algorithm has been derived that uses the threshold level and gives a reasonable number of handoffs. A technique for adapting the algorithm is also suggested. R.Rezaiifar [128] formulated the handoff problem in a stochastic control framework. A Markov decision process formulation is used, and optimum handoff strategies are derived by dynamic programming. The optimization function includes a cost for switching and a reward for improving the quality of the call. The optimum decision is the hysteresis value representing the difference in RSSs from the BSs.

2.9.2 Pattern Recognition Based Handoff Algorithms

The Pattern recognition (PR) identifies meaningful regularities in noisy or complex environments. These techniques are based on the idea that the points that are close to each other in a mathematically defined feature space represent the same class of objects or variables. Explicit PR techniques use discriminant functions that define (n-1) hyper surfaces in an n-dimensional feature space. The input pattern is classified according to their location on the hypersurfaces. Implicit PR techniques measure the distance of the input pattern to the predefined representative patterns in each class. The sensitivity of the distance measurement to different representative patterns can be adjusted using weights. The clustering algorithms and fuzzy classiffiers are examples of implicit methods. The environment in the region near cell boundaries is unstable, and many unnecessary handoffs are likely to occur. The PR techniques can help reduce this uncertainty by efficiently processing the RSS measurements. H.Loyoza [64] formulates the handoff problem as a pattern recognition problem.

2.9.3 Prediction-based Handoff Algorithms

The prediction-based handoff algorithms use the estimates of future values of handoff criteria, such as RSS. R.Sanakar [54] has discussed this technique and shows it to be better than the relative signal strength algorithm and the combined absolute and relative signal strength algorithm via simulations. An adaptive prediction based algorithm has been proposed to obtain a tradeoff between the number of handoffs and the overall signal quality [54]. Signal strength based handoff algorithms can use path loss and shadow fading to make a handoff decision. The path loss depends on distance and is determinate. The shadow fading variations are correlated and hence can be predicted. The correlation factor is a function of the distance between the two locations and the nature of the surrounding environment [167]. This prediction based algorithm exploits this correlation property to avoid unnecessary handoffs. The future RSS is estimated based on previously measured RSSs using an adaptive FIR filter. The FIR filter coefficients are continuously updated by minimizing the prediction error. Depending upon the current value of the RSS (RSS_c) and the predicted future value of the RSS (RSS_p), handoff decision is given a certain priority. Based on the combination of RSS_c and RSS_p, hysteresis may be added if it will not affect the handoff performance adversely. The final handoff decision is made based on the calculated handoff priority.

2.9.4 Neural Handoff Algorithms

Most of the reported neural techniques have shown only preliminary simulation results or have described methodologies without the simulation results. These techniques have used simplified simulation models. Learning capabilities of several paradigms of neural networks have not been utilized effectively in conjunction with handoff algorithms to date. The author G.Liodakis [47] presents a signal strength based handoff initiation algorithm using a binary hypothesis test implemented as a neural network. However, simulation results are not presented. D.M.Rodriguez [39] suggested a methodology based on an ANN in micro cellular communication system. Preliminary simulation results show that this methodology is suitable for multicriteria handoff algorithms.

2.9.5 Fuzzy Handoff Algorithms

The decision making capability of fuzzy logic has been applied to handoff algorithm discussed in [167]. Y.Kinoshita [167] suggested a fuzzy handoff algorithm. The fuzzy handoff algorithm has been shown to possess enhanced stability (i.e., less frequent handoffs). A hysteresis value used in a conventional handoff algorithm may not be enough for heavy fadings, while fuzzy logic has inherent fuzziness that can model the overlap region between the adjacent cells, which is the motivation behind this fuzzy logic algorithm. H.Lozoya [64] used a fuzzy classifier to process the signal strength measurements to select a BS to serve a call. The performance of this algorithm in a microcellular environment is evaluated.

H. Maturino-Lozoya et al in [32] discussed a handoff procedure using fuzzy logic. It incorporates signal strength, distance, and traffic. Preliminary simulation results are presented. D.Rodriguez et al [38] explained the concept of cell membership degree to handoff. The methodology proposed in this paper allows systematic inclusion of different weight criteria and reduces the number of handoffs without excessive cell coverage overlapping. It is shown that the change of RSS threshold as a means of introducing a bias is an effective way to balance traffic while allowing few or no additional handoffs. It is suggested that a combination of range and RSS modified by traffic weighting might give good performance. Different fuzzy composition methods to combine the cell membership degrees of different criteria methods are investigated. Effects of changes in the cell membership degrees on handoff performance have been evaluated.

2.10 Introduction to Soft Handoff in CDMA

Soft handoff (SHO) is a "make before break" connection, i.e., the connection to the old BS is not broken until a connection to the new BS is made. SHO utilizes the technique of macroscopic diversity. Macroscopic diversity is a technique in which transmissions from an MS are received at different BSs and then used to obtain a good quality communication link [34]. The same concept can be used at the MS too. Macroscopic diversity is based on the principle of diversity combining that assumes that different BSs transmit and receive the same call with uncorrelated signal paths. Macroscopic diversity can provide good performance in terms of RSS and SIR for an interference limited system. It is shown in [129] that a four-branch macroscopic diversity can provide a 13 dB improvement in RSS and a 15 dB improvement in SIR (for a path loss exponent of 4 and a 10 dB shadow fading standard deviation). Some of the diversity combining techniques include selection diversity, maximum ratio combining, and equal gain combining [34]. The MSs must decode the signals from all base stations, which may be using the same or different channels. Such handoffs are called single channel SHO (SCSHO) and multiple channel SHO (MCSHO), respectively [122]. Single Channel SHO (SCSHO). In this type of SHO, each participating base station transmits on the same channel. For high traffic situations, SCSHO may success. Multichannel SHO (MCSHO). In this type of SHO, participating BSs use different channels. P.E Ostling et al [122] investigated the effect of simulcasting in macrocellular and microcellular systems. Simulcasting is an example of SHO in which the MS is simultaneously connected to several BSs in the border region between the cells. The BSs participating in SHO simulcast (i.e., simultaneously transmit) replicas of the same signal to the MS.There are several variations of SHO. The term soft handoff is used when old and new BSs belong to two different cells. The term softer handoff is used when the two signals correspond to the two different sectors of a sectorized cell [136]. When soft and softer handoffs occur simultaneously, the term soft-softer handoff is used. In particular, proper selection of the SHO region and its associated parameters can avoid the ping-pong effect common in hard handoff [34]. A disadvantage of SHO, the mobile undergoing SHO occupies channels between different BSs and the switch (MSC). Moreover, SHO tends to increase the traffic in the wired channels in a fixed network. The greater the number of BSs involved in SHO, the more traffic in the fixed network. Also, SHO requires an MS receiver capable of decoding multiple copies of the transmitted signal. Soft Handoff in Practice SHOs are common in CDMA. For IS-95, the BSs involved in SHO can transmit on the same frequency and Walsh code, and the resultant signals are handled by the receiver as additional multipaths to be incorporated into the decoded signal [147]. SHOs are imperceptible to users and require a tight synchronization between all BSs in the network to maintain data synchronization after handoff. The CDMA systems support this function by using the global positioning system (GPS) to provide a master clock.

2.11Conclusion

The diversity technique to improve the quality of received signal has been discussed. The different types of the diversity and resolvable path have been described. The diversity combining method can improve the bit error rate performance of the communication link. When a mobile move from one base station to another base station, the mobile station receive signal from both station simultaneously and combine these signal to improve performance.

A high performance handoff algorithm can achieve many of the desirable features by making appropriate tradeoffs. However, several factors such as topographical features, traffic variations, propagation environments, and system-specific constraints complicate the task of handoff algorithms. Different system deployment scenarios present different constraints on handoff procedure. Handoff algorithms with a specific set of parameters cannot perform uniformly well in different communication system deployment scenarios since these scenarios impose distinct restrictions and specific environments on the handoff process. These system structures are expected to co-exist in future wireless communication systems and warrant a substantial study. The issues involved in the design and analysis of handoff algorithms were thoroughly described. In particular, different handoff criteria were analyzed. Both the conventional and emerging approaches for designing handoff algorithms were discussed. Several metrics have been discussed and used to quantify the handoff related system performance. A brief account of handoff performance measures was given.

CHAPTER 3

Bit Error Rate Analysis of Spread Spectrum and Antenna Diversity

3.1 Introduction

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CHAPTER 3

Bit Error Rate Analysis of Spread Spectrum and Antenna Diversity

3.1 Introduction

The diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. There are wide ranges of diversity implementations, which are practical and provide significant link improvement with little added complexity. The spread spectrum and antenna diversity performance are related to the fading phenomenon. The fading may be two types, namely, Small scale and large scale fading. The small scales fading are caused by multiple reflections from the surroundings in the vicinity of mobile. If two antennas are separated by a fraction of meter, one may receive a weak signal while the other receives a strong signal. The receiver can select the best signal by using multiple antennas and can mitigate small scale fading effects. This form of diversity is known as antenna diversity due to use of the multiple antenna. This form of diversity is also called microscopic diversity.

The large scale fading is caused by shadowing due to variations in both the terrain profile and the nature of surroundings or base station. In such area, more than one base stations are involved in the communication. Some base station may be shadowed by the surrounding building or by terrain. By selecting a base station which is not shadowed by the mobile can improve the average signal to noise ratio. This is also called macroscopic diversity. This is useful at the base station receiver. The base station receiver uses antenna diversity, in which, antennas that are sufficiently separated in space. The base station is able to improve the link performance by selecting the antenna at the base station, with the strongest signal from the mobile. It is proposed to analyze the bit error rate of the spread spectrum with maximum ratio combining and antenna with selection diversity combining. The performance analysis of the proposed system is evaluated in terms of the bit error rate. The closed form of the expression of probability of bit error rate has been derived for the order of diversity.

3.2. Review on Diversity & Bit Error Rate

The DS-CDMA is currently the area of much attention in the research and development of personal, indoor and mobile communication systems for its multiple access capability and high capacity [40]. However, the multipath fading effect often causes a fundamental limitation to the system performance e.g., signal to noise ratio, bit error rate. The diversity combining is well recognized as an effective technique to enhance signal to noise ratio and to reduce the bit error rate attribute to this fading effect. The purpose of diversity is to supply to the receiver several replicas of the same information signal transmitted over independently fading paths. There are several diversity propagation mechanisms for achieving independently fading signals, which may include: antenna (space), frequency, angle, polarization, time and multipath diversity. In DS-CDMA application, signal spectrum spreading caused by the multipath fading can be resolved to become discrete fading signal branches due to the wideband nature of the signal. The receiver can exploit this multipath diversity characteristic by diversity combining to mitigate the fading effect. In spread spectrum systems, selection, maximal ratio and equal gain combining methods are generally used. Among the three methods, maximal ratio combining gives the best performance while the selection diversity is the simplest of all.

Accordingly, numerous research papers have been reported on the study of the system performance of a DS-CDMA system with diversity combining in a variety of multipath fading channel models [112,103,66,137,86,161]. The author N.L.B. Chan[112], has evaluated the performance of the reverse link of a code division multiple access cellular system. The parameter used is the signal-to-noise ratio (SNR) for a received signal is used to measure the performance of the reverse link. The authors H. Erben et al [65] have discussed an exact analytical solution to calculate the mean BER performance of an hybrid selection combining (SC)/maximal ratio combining (MRC) RAKE receiver structure applying the DPSK modulation technique. The author Y.Roy et al [168] presented combining schemes for selection diversity reception with multiple antennas for indoor radio channels. For those combining schemes, a reduction in complexity is achieved by limiting the number of combined signals to small values and by increasing the number of received signals. Bit error rate (BER) performance of binary phase shift keying (BPSK) with combining of selected signals (CSS) and BER performance of differential BPSK with CSS are analyzed for slow fading and Rayleigh-distributed envelope statistics. The authors K.T. Wu and S.A. Tsaur[86], have evaluated Average error probability and outage probability for asynchronous binary direct sequence spread-spectrum multiple access communications through slow nonselective Nakagami fading channels are evaluated for no diversity and diversity receptions.

In this analysis, it is proposed to evaluate the combined effect of antenna with selection diversity and spread-spectrum with Maximum Ratio Combining for DS-CDMA using BPSK modulation and non-coherence demodulation over a frequency selective multipath Rayleigh fading channel.

3.3 System Model for Bit Error Rate

Figure3.1 shows the block diagram of the diversity receiver system. Only one transmitter was illustrated in the figure, but a total number of K simultaneous active transmitters are present. For each user, it employs a single transmitting antenna and U receiving antenna for achieving antenna (space) diversity. Receiving antenna should be separated by distances large enough, for example, greater than several wavelengths, to obtain uncorrelated multiple fading components. At each receiving antenna site (also known as a port), L independent diversity branches are obtained by resolving the selective channel paths with spread spectrum signaling. Since the reflections for components with an excess delay difference greater than a few hundred nanoseconds are due to different physical structures, it is assumed that they are uncorrelated. This inherent spread spectrum (SS) multipath diversity is owing to the wide band nature of the spread spectrum signal.

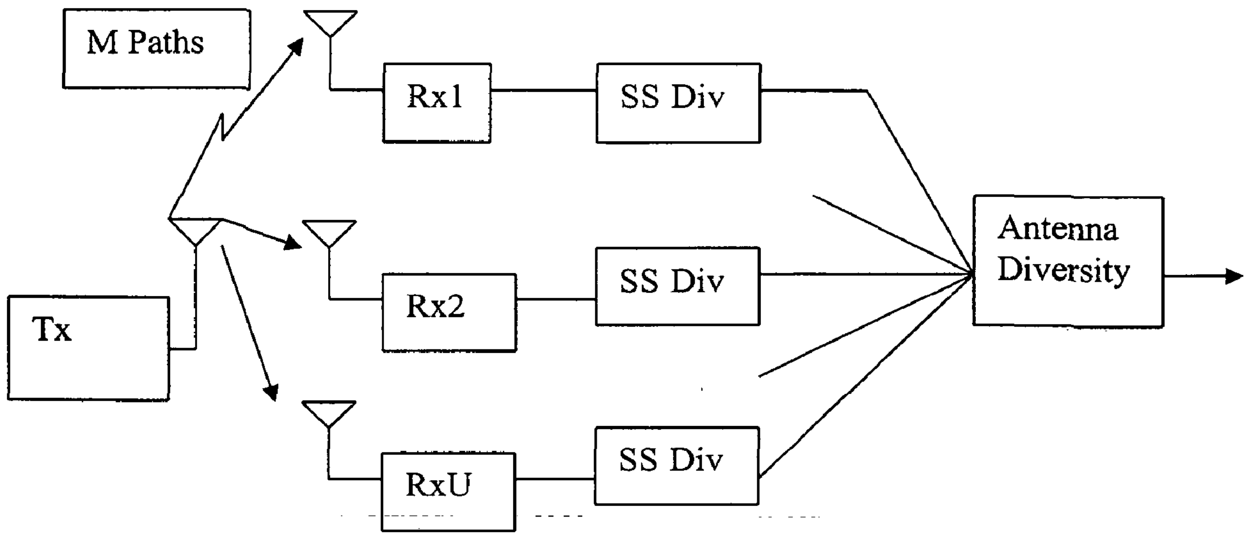

Figure 3.1 Block Diagram of diversity receiver

The direct-sequence BPSK transmitted signal of the ith transmitter has the following form: $S_i(t) = \sqrt{\frac{2E_s}{T}} a_i(t) b_i(t) Cos(\omega_c t + (2i-1)\Pi/2)$ i=1,2 (3.1)

Where E_s is the transmitted power which is common to all transmitters, $a_i(t)$ is the DS pseudorandom spreading code, $b_i(t)$ is the data code, ω_c is the carrier radian frequency and i is the carrier phase of the i_{th} transmitter. Both $a_i(t)$ and $b_i(t)$ are the independently identical distributed sequences of unit amplitude bipolar rectangular pulses. One period of spreading code consists of N chips, each of duration T_c and assumed to be synchronized to the data code so that the data bit duration T_b is given by $T_b = NT_c$. The channel model we consider in this study is a frequency-selective slow-fading multipath Rayleigh channel. In a frequency-selective multipath channel, the signal has a bandwidth greater than the coherence bandwidth of the channel, and the signal is subjected to different gains and phase shifts across the channel. The contributions of the involved paths may add up constructively as well as destructively. The signal is severely distorted in such a channel. In a slow-fading channel, the signaling interval is smaller than the coherence time of the channel. The channel attenuation and phase shifts are essentially fixed for the duration of at least one signaling interval in this case, which implies that the channel characteristics vary sufficiently slowly that they can be measured. The delay differences between any two different paths are larger than one chip duration T_c in a frequency-selective channel. A resolution of T_c thus can be obtained in the multipath delay profile. If the total rms delay spread is T_m, then $M = \text{int}\left[\frac{T_m}{T_c}\right] + 1$ is the maximum number of the discrete resolved signal branches and equal to the maximum order of diversity that can be used to combat the multipath fading. In the proposed work spread spectrum diversity with maximum ratio combining and antenna diversity with selection diversity have been analyzed and the combined effect on the bit error rate of both the schemes have been analyzed.

3.4.1 Maximal Ratio Combiner

There are several incoming signal as an input to the combiner. These signals are combined in a linear way to achieve the maximum output [117].

The combined signal at the MRC output is

$$r_k = \sum_{k=1}^{L} a_k r_k \tag{3.2}$$

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The noise power at the MRC output is

$$N_R = N \sum_{K=1}^{L} a_k^2 \qquad (3.3)$$

If we weight $a_k = {r_k}/{N}$, where N is the noise power at the input of the MRC then the SNR at the output of the combiner will be maximized. Assuming that all paths have equal strength then the SNR, at the output of MRC can be expressed as

$$\bar{\gamma}_m = L\gamma_p \qquad (3.4)$$

It is seen from equation (3.4) that the SNR performance at the output of the MRC outperforms the SDC, which only selects the best of the input SNRs. For L = 4 the SNR at the output of MRC is about 3 dB better than the SNR at the output of SDC. The SNR at the output of MRC is better than can be achieved with any other linear combiner. The SNR at the output of the MRC is the sum of all the SNR's of each path at the input. Note that the SNRs at the input are random variables with a Rayleigh distribution. The output PDF can be determined via the convolution or the characteristic function. In our case, to deal with linear addition of more than two PDFs, we utilize the characteristic function. Let the mean SNR be γ_p and its instantaneous SNR be γ then

$$E[e^{jv\gamma}] = \psi(jv) = \frac{1}{(1 - jv\gamma_p)} \qquad (3.5)$$

where E[ ] is the expectation and ψ is the characteristic function. The dummy variable v is real and $j = \sqrt{-1}$. The characteristic function for L diversity paths with Rayleigh distribution, assuming each path is statistically independent and each of them has equal strength is

$$\psi_L(jv) = \frac{1}{(1 - jv\gamma_p)^L} \qquad (3.6)$$

The PDF of γ at the output of the MRC is the inverse Fourier transform of equation (3.6) which is easily shown to be

$$p(\gamma) = \frac{\gamma^{L-1} e^{-\frac{\gamma}{\gamma_p}}}{(L-1)!\,\gamma_p^L} \tag{3.7}$$

The BER performance of MRC can also be obtained following a similar procedure in deriving the BER performance of SDC. After some algebraic manipulation we obtain the BER as a function of SNR for MRC with PSK modulation scheme as in [118]

$$P_e = (\frac{1-\mu}{2})\sum_{K=0}^{L-1}(\frac{L-1+k}{k})\left[\frac{1+\mu}{2}\right] \tag{3.8}$$

Where in this case

$$\mu = \sqrt{\frac{\gamma_p}{1+\gamma_p}} \tag{3.9}$$

It can be shown that, the SNR at the output of the Maximal Ratio Combiner (MRC) is the best among all the diversity combiners [118].

3.4.2 Selection Diversity Combiner

The selection diversity combiner has several incoming signal on its input. The Selection Diversity Combiner (SDC) the diversity path having the strongest signal is selected, so the output of the combiner is the same as that of the strongest diversity path [71]. In this case only one $a_k = 1$ at any time, others are all zero. Since in practical systems the signal always is combined with noise, this implies that for identical noise power, the combiner should always select the path having the highest signal to noise ratio (SNR). Let us define for each diversity path two SNR values:

γ_s = Instantaneous mean signal power/ mean noise power (3.10)

and

γ_p = Mean signal power / Mean noise power (3.11)

Making assumptions that all diversity paths are uncorrelated (statistically independent) and assuming they are represented as narrow-band Gaussian processes, then their envelopes are Rayleigh distributed. Then the probability density function (PDF) of the signal envelope r_k in the k-th path can be written as in [91]

$$p(r_k) = \frac{2r_k}{\sigma_k^2}\exp\left(-\frac{r_k^2}{\sigma_k^2}\right) \quad (3.12)$$

Where σ^2_k is the variance of the distribution.

Using a PDF transformation it is easy to show that the PDF of γ for a given path is

$$p(\gamma) = \frac{1}{\gamma_p}\exp\left(-\frac{\gamma}{\gamma_p}\right) \quad (3.13)$$

For a single path, the probability of the SNR (γ) being less than or equal to any given value γ_s is the cumulative distribution function (CDF) of γ_s and can be written as

$$F(\gamma_s) = \Pr\{\gamma \le \gamma_s\} = \int_0^{\gamma_s} p(\gamma)d\gamma$$

Or

$$F(\gamma_s) = 1 - \exp\left(-\frac{\gamma_s}{\gamma_p}\right) \quad (3.14)$$

For L diversity paths, it follows that

$$\Pr\{\gamma_1, \gamma_2, \ldots\ldots \gamma_L \le \gamma_s\} = \prod_{k=1}^{L}\left(1 - \exp\left(-\frac{\gamma_s}{\gamma_{pk}}\right)\right) \quad (3.15)$$

Assuming that all paths have equal mean SNR ($\gamma p1 = \gamma p2 = \ldots\ldots\ldots = \gamma_p$) and they are statistically independent then the CDF of γ_s at the output of the SDC is equal to the multiplication of the CDF of each path and can be written as

$$\Pr\{\gamma_1, \gamma_2, \ldots\ldots\ldots \gamma_L \le \gamma_s\} = \left(1 - \exp\left(-\frac{\gamma_s}{\gamma_p}\right)\right)^L \quad (3.16)$$

The PDF of γ_s at the output of the SDC is the derivative of equation (3.8)

$$P(\gamma_s) = \frac{L}{\gamma_p}\exp\left(-\frac{\gamma_s}{\gamma_p}\right)\left(1 - \exp\left(-\frac{\gamma_s}{\gamma_p}\right)\right)^{L-1} \quad (3.17)$$

From equation (3.17) we can find easily the average SNR at the output of the SDC and the bit error rate performance of the system. The average SNR $\bar{\gamma}_s$ at the output of the SDC, can be obtained from

$$\bar{\gamma}_s = \int_0^\infty \gamma_s p(\gamma_s) d\gamma$$

It can be shown as in [114] that

$$\gamma_s = \bar{\gamma}_p \sum_{k=1}^{L} \frac{1}{K} \quad (3.18)$$

From equation (3.18) it can be seen by numerical evaluation that if there are 4 resolvable paths (L = 4) then the SNR improvement at the output of the SDC is 3.2 dB, or about twice the average SNR of the path.

General procedures for evaluating BER when fading is present in a channel are as follows:

1. Evaluate the BER assuming the signal strength is constant, and that only Gaussian noise is present. This BER is known as the Conditional Error Probability, $p_{ECP}(\gamma \mid \gamma_s)$.

2. Average the $p_{ECP}(\gamma \mid \gamma_s)$ with respect to a PDF for the signal strength.

Hence the BER as a function of S/N in a fading channel can be expressed a

$$P_e = \int_0^\infty P_{CEP}(\gamma \mid \gamma_s) p(\gamma_s) d\gamma_s \tag{3.19}$$

The conditional error probability for several signaling systems has been discussed in many research article such as [118].

For coherently demodulated Phase Shift Keying (PSK) and Frequency Shift Keying (FSK), the conditional error probability is

$$P_{CEP}(\gamma \mid \gamma_s) = \frac{1}{2} erfc(\sqrt{a\gamma_s}) \tag{3.20}$$

Where erfc (x) is defined as $erfc(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$

For a non-coherent signaling system, the conditional error probability is

$$P_{CEP}(\gamma \mid \gamma_s) = \frac{1}{2} e^{-a\gamma_s} \tag{3.21}$$

Here a = 1 for a PSK signal.

The BER for the SDC with a coherent signaling system can be expressed using equation (3.20) and fading channel statistic as in equation (3.19).

$$P_e = \int_0^{\infty} \frac{1}{2} erfc\,(\sqrt{a\gamma_s})\,p(\gamma_s)\,d\gamma_s \qquad (3.22)$$

After some algebraic manipulation it can be shown [118] that the error probability of the SDC as a function of SNR per diversity path is

$$P_e = \frac{\gamma_p}{2} \sum_{k=0}^{L-1} (-1)^k \left(\frac{L-1}{K}\right) \frac{1}{(1+k)} (1 - \frac{1}{\sqrt{1 + \frac{1+k}{a\gamma_p}}}) \qquad (3.23)$$

3.4 System Parameters

The system parameters are diversity order and mean signal to noise plus interference ratio. it is assumed that the order of spread spectrum diversity is L and the order of the antenna diversity is U. The frequency-selective multipath Rayleigh fading channel has been considered for DS-CDMA communications. The mean signal-to-noise plus interference power ratio per combined path when Gold codes are used as spread pseudorandom codes is given [103] by-

$$\bar{\gamma}_k = \frac{E_b}{2KLE_b / 3N + N_0} \qquad (3.24)$$

Where $E_b = 2\rho PT_b$ the received signal energy per bit.

L= order of antenna diversity

3.5 Bit Error Rate Analysis of Spread Spectrum & Antenna Diversity

This analysis utilizes the previous work done by the author on Maximum ratio combiner and selection diversity combiner [71,17]. It is proposed to analyze the combined effect MRC & SDC combiner on the Bit Error rate of the system.

The configuration involves the combination of the spread spectrum with MRC and antenna with SDC scheme. This is called the MRC-SDC configuration.

3.5.1 Bit Error Rate Analysis of MRC-SDC Configuration

The combiner configuration is the MRC-SDC configuration shown in figure 3.2. In this configuration the SDC will select the base station with the highest instantaneous SNR.

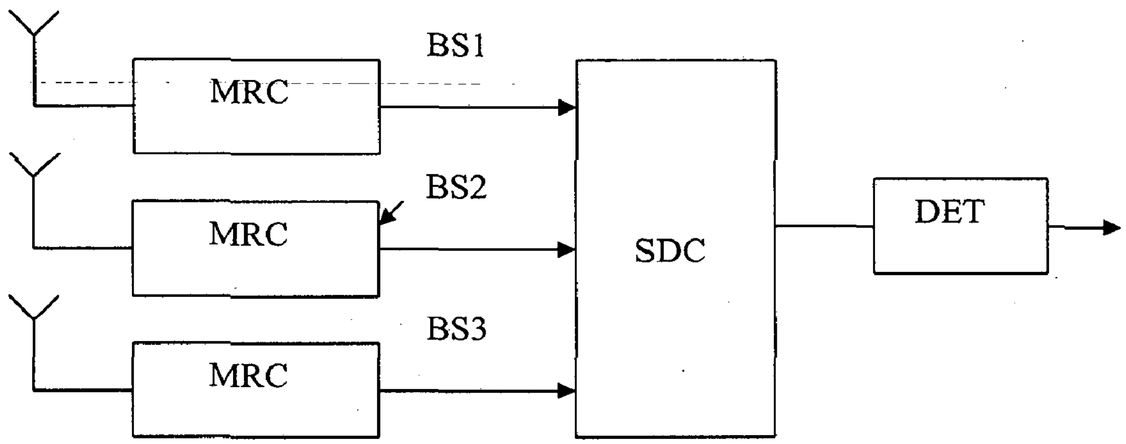


Figure 3.2: MRC-SDC Configuration

In our analysis, it is assumed that each base station experiences independent fading and hence their output signals are uncorrelated. In this case the fading process has a Rayleigh distribution. The modulation scheme is coherent PSK and is detected by the detection unit (DET). The BER of the MRC-SDC configuration can be obtained by averaging the conditional error probability over the PDF of the SNR for a fading channel as previously described. To assess $F(\gamma)$ for several BS's, it is necessary to find the probability of the SNR being less than or equal to a given SNR for the given BS. If we define γ_b as the average SNR at the output of a BS and γ_p as the average SNR for each received path, the PDF of γ_b for L paths is the same as in equation (3.7) and is rewritten as

$$p(\gamma_b) = \frac{\gamma_b^{L-1} e^{-\frac{\gamma_b}{\gamma_p}}}{(L-1)!\,\gamma_p^L} \tag{3.25}$$

The CDF of the SNR of any BS being less than or equal to any given SNR value γ_s is

$$F(\gamma_s) = \Pr\{\gamma \le \gamma_s\} = \int_0^{\gamma_s} p(\gamma)\,d\gamma \tag{3.26}$$

or

$$F(\gamma_s) = \frac{\Gamma(L,0,\gamma_s/\gamma_p)}{(L-1)!} \tag{3.27}$$

where $\Gamma(L,0,\gamma_s/\gamma_p)$ is the incomplete Gamma function and is defined as

$$\Gamma(L, z_0, z_1) = \int_{z_0}^{z_1} t^{L-1} e^{-t}\,dt$$

Equation (3.27) can be extended to the case of N base stations having SNR less than or equal to γ_s. Assuming the BS outputs are uncorrelated then the CDF at the output of the SDC, $F_N(\gamma_s)$ is the product of the CDF of each BS. For equal strength paths,

$$F_N(\gamma_s) = \left(\frac{\Gamma(L,0,\gamma_s/\gamma_p)}{(L-1)!}\right)^N \tag{3.28}$$

To find the PDF of SNR for the MRC-SDC configuration for N identical BS is equivalent to finding the derivative of equation (3.28).

$$p_N(\gamma_s) = \frac{\left(\frac{\gamma_s}{\gamma_p}\right)^{(L-1)} N\left(\frac{\Gamma(L,0,\gamma_s/\gamma_p)}{(L-1)!}\right)^{(N-1)}}{\gamma_p e^{\gamma_s/\gamma_p}(L-1)!} \tag{3.29}$$

The BER of this MRC-SDC configuration is obtained following the procedure as in obtaining equation (3.22). In this case, a PSK modulation scheme is used and take L = 2 diversity paths and consider N = 1,2,3 BS's. The derivation of the BER for N=1 has been shown below.

The PDF p (γ_s) of SNR of an MRC-SDC configuration can be obtained from equation

$$P(\gamma_s) = \frac{d}{d\gamma_s}\left(\frac{\tau(L,0,\frac{\gamma_s}{\gamma_p}}{(L-1)!}\right)^N \tag{3.30}$$

For N=1 and L=2,

$$P(\gamma_s) = \frac{d}{d\gamma_s}(1 - e^{-\frac{\gamma_s}{\gamma_p}}(1 + \frac{\gamma_s}{\gamma_p})) \tag{3.31}$$

Let $A_1 = 1 - e^{-\frac{\gamma_s}{\gamma_p}}$

$$A_2 = \frac{\gamma_s}{\gamma_p} e^{-\frac{\gamma_s}{\gamma_p}}$$

Consider coherent PSK signaling. The bit error rate (BER) for MRC-SDC configuration for N=1 and L=2 is written as-

$$P_e = \int_0^\infty (\frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\gamma_s}}^\infty e^{-\frac{t^2}{2}} dt) d(A_1 - A_2) \tag{3.32}$$

Let

$$I_{A_1} = \int_0^{\infty} \left(\frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\gamma_s}}^{\infty} e^{-\frac{t^2}{2}} dt \right) d(A_1) \tag{3.33}$$

$$I_{A_2} = \int_0^{\infty} \left(\frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\gamma_s}}^{\infty} e^{-\frac{t^2}{2}} dt \right) d(A_2) \tag{3.34}$$

Now, Evaluating I_{A_1} using partial integration, obtain

$$I_{A_1} = \frac{1}{\sqrt{2\pi}} \left(\sqrt{\frac{\pi}{2}} - \frac{\sqrt{\frac{\pi}{2}}\sqrt{\gamma_p}}{\sqrt{1+\gamma_p}} \right) \tag{3.35}$$

Also

$$I_{A_2} = \frac{1}{\sqrt{2\pi}} \left(\frac{\sqrt{\frac{\pi}{2}}\sqrt{\gamma_p}}{2(\sqrt{1+\gamma_p})^3} \right) \tag{3.36}$$

Using above equations, it can be shown that BER for MRC-SDC configuration for N=1 and L=2 using PSK is

$$P_e = I_{A_1} - I_{A_2}$$

Or

$$p_e(\gamma_p) = \frac{1}{2} - \frac{(3+2\gamma_p)\sqrt{\gamma_p}}{4(1+\gamma_p)^{3/2}} \tag{3.37}$$

For N=2 and L=2:

$$p_e(\gamma_p) = \frac{1}{2} - \frac{(3+2\gamma_p)\sqrt{\gamma_p}}{4(1+\gamma_p)^{3/2}} + \frac{(27+20\gamma_p+4\gamma_p^2)\sqrt{\gamma_p}}{8(2+\gamma_p)^{5/2}} \tag{3.38}$$

For N=3, L=2

$$p_e(\gamma_p) = \frac{1}{2} - \frac{(3 + 2\gamma_p)\sqrt{\gamma_p}}{4(1+\gamma_p)^{3/2}} + \frac{(27 + 20\gamma_p + 4\gamma_p^2)\sqrt{\gamma_p}}{8(2+\gamma_p)^{5/2}} + \frac{(393 + 306\gamma_p + 84\gamma_p^2 + 8\gamma_p^3)\sqrt{\gamma_p}}{16(3+\gamma_p)^{7/2}}$$

(3.39)

The BER for the MRC-SDC configuration is shown in figure 3.3, 3.4,3.5 for N = 1, 2, 3.It is seen from figure 3.5 that a gain of about 7 dB at BER = 10^{-3} has been obtained. if three base stations are used and each of them are received as statistically identical diversity paths. The gain reduces to 5 dB if there are only two base stations.

3.6 Results & Discussion:

The bit error rate of the maximum ratio combining and selection diversity combining has been plotted in the graph figure 3.3, figure3.4 and figure3.5 as shown below. The BER performance has been analyzed in a multipath Rayleigh fading channel for two base station diversity configurations. Each base station uses an MRC scheme. The detection block is located at the diversity combiner site. It is assumed that each base station receives the same average SNR from a mobile station. The attenuation due to spatial location with respect to the base station is ignored and only the Rayleigh fading effect taken into account. This simplification may have application in the micro cell environment. Based on the conditions and assumptions mentioned above, the BER performance of the MRC-SDC configuration has been analyzed analytically and the results are plotted in the graph figure 3.3, figure 3.4 and figure 3.5. General trend is that probability of error decreases as the signal to noise ratio increases. For lower SNR values (at SNR ≈ 5 dB) the performance for three configurations is almost the same. It is concluded from figure 3.5 that if the number of base station increases the BER performance of the MRC-SDC configuration is improved slightly. On the other hand, increasing the number of base stations from one to three base stations in the MRC-SDC configuration, can improve the system performance (4 dB at BER 10^{-5}) as shown in figure 3.5.

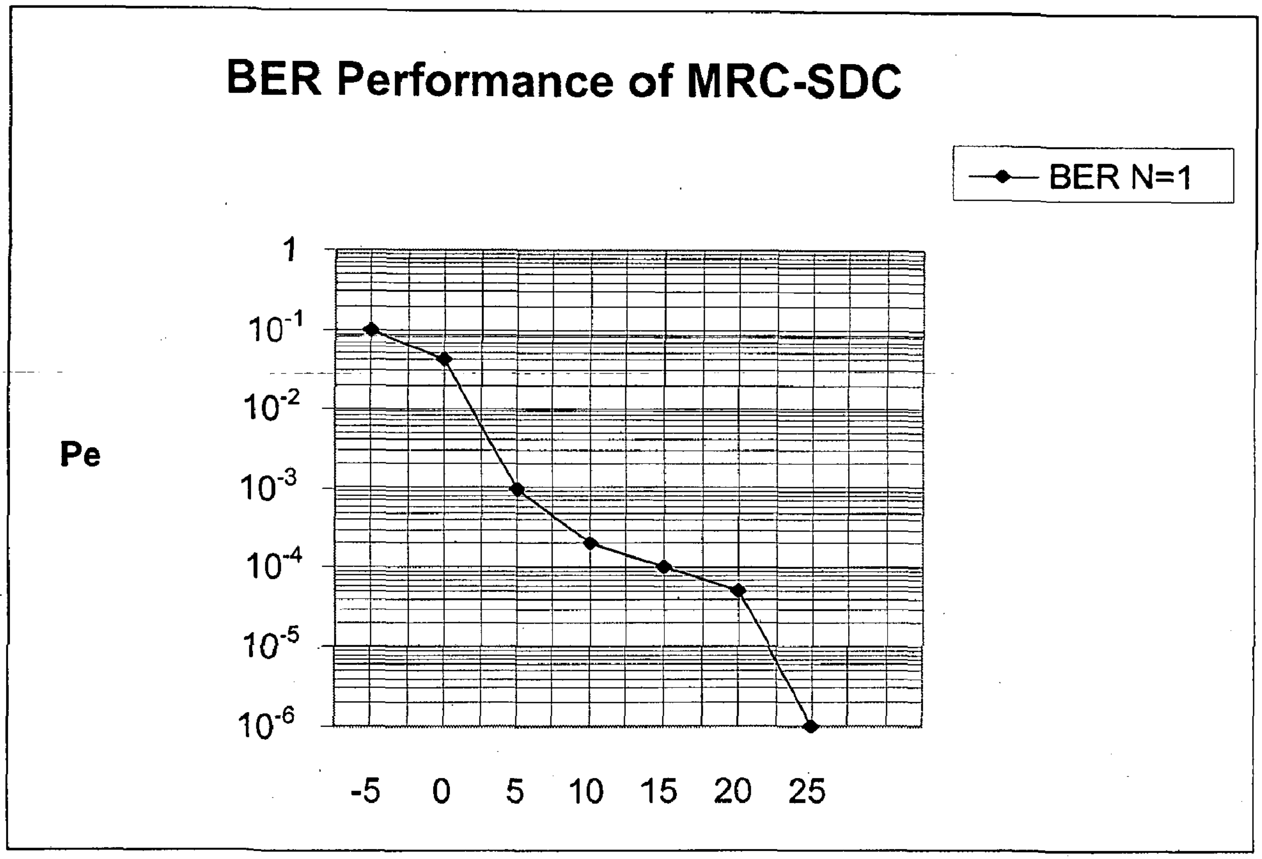


Figure 3.3 Bit Error Rate performance of MRC-SDC, N=1

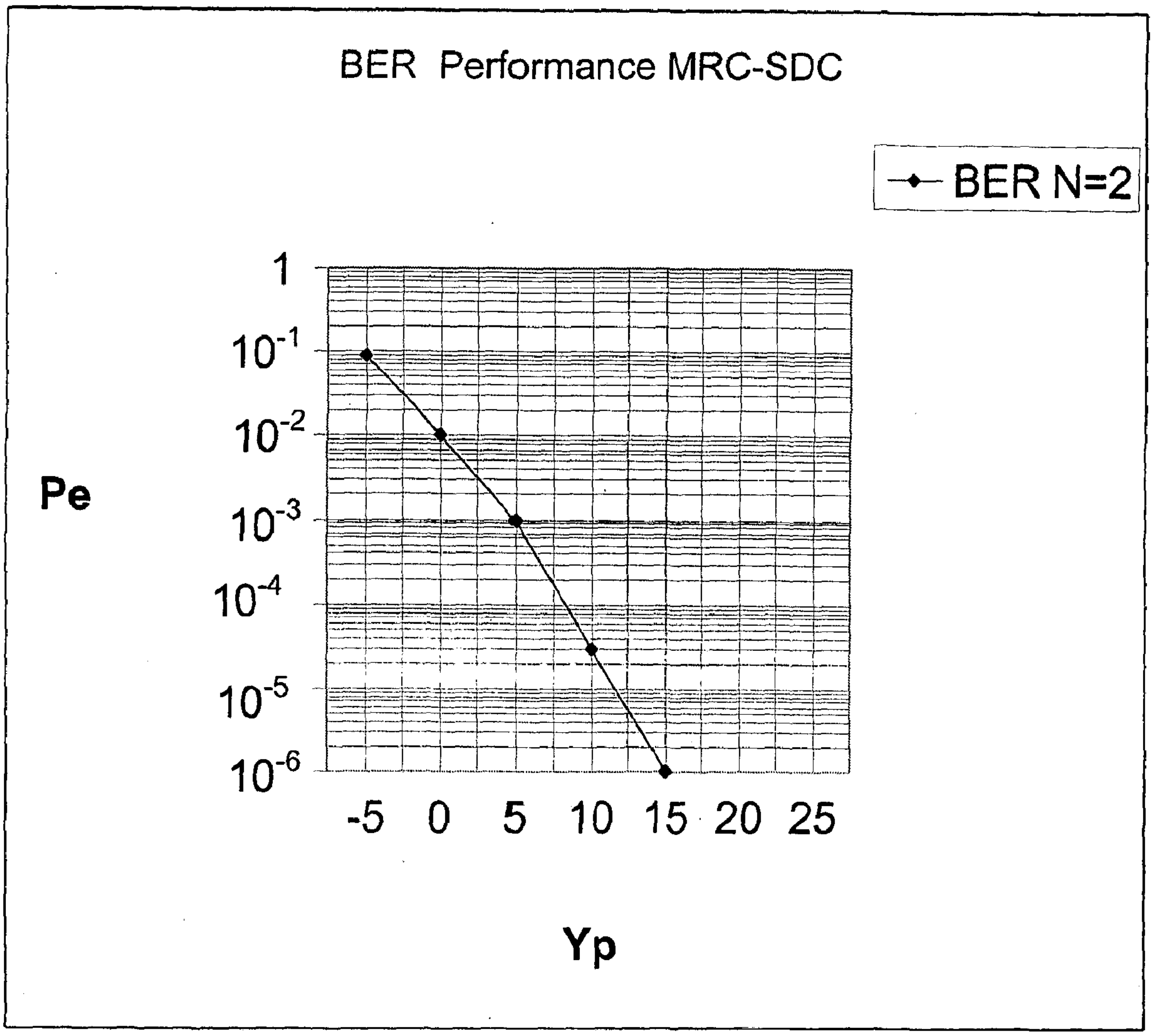


Figure 3.4 Bit Error Rate performance of MRC-SDC, N=2

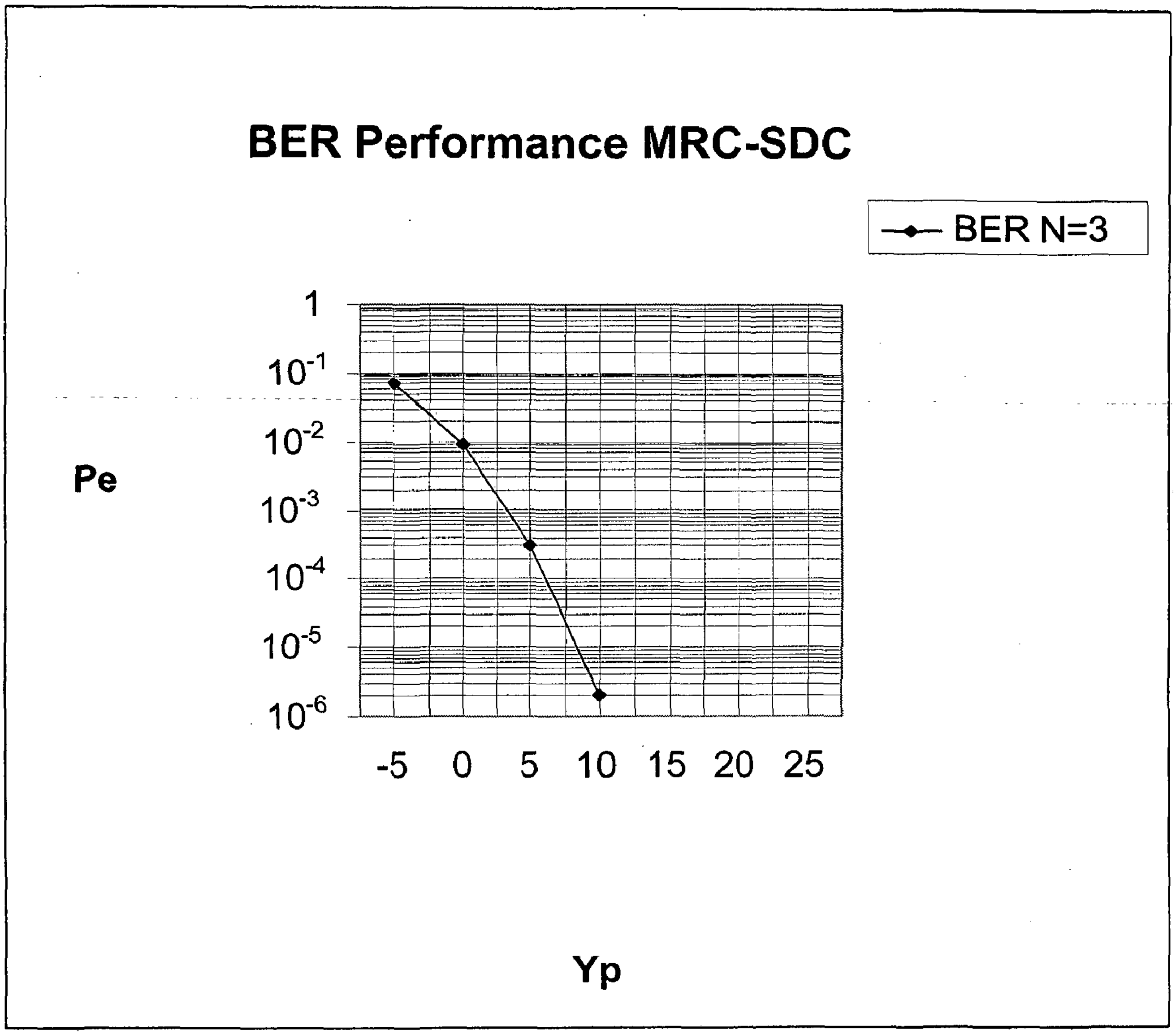


Figure 3.5: Bit Error Rate performance of MRC-SDC, N=3

Chapter 4

Performance Analysis of Switched Diversity in CDMA

4.1 Introduction

4.2 System Model of Switched Diversity

4.3 Bit Error Rate Performance of Switched Diversity with Threshold

4.4 The Switched Diversity Combining with Fuzzy Threshold Control

4.5 Results & Discussion

Chapter 4

Performance Analysis of Switched Diversity in CDMA

4.1 Introduction

It is well known that multipath fading is one of the main causes of performance degradation in a CDMA mobile radio system [143]. A widely recognized technique for combating fading effects in CDMA, is the use of a diversity combiner [143,162,9,10,169],.The two or more radio links of a diversity channel are presumed to be statistically independent. There are basically four diversity combining methods, maximal-ratio combining, equal gain combining, selective combining and switched combining. The maximal-ratio combining and equal-gain combining require very complicated analog circuitry, thus, having hardly been used in practice. The maximum ratio and equal gain combining have excellent performance. Selective combining and switched combining are two potential techniques in practice due to their simplicity in implementation with moderate performance. Typically, selective combining requires multiple receivers, one for each branch. When the channel variation is very slow, selective combining may be achieved with a reduced number of receivers [10,169]. A.Arasteh [10] described the received signal measurement and selection has been performed with the aid of a pre-amble. Thus, even one receiver could offer an approximate realization of selective combining. However, very often pre-amble [10] and/or post-amble [169] aided combining techniques are only effective in a very slow fading environment. Similarly, switched diversity combining is less costly since it needs only one receiver. However, switched diversity has better performance if the threshold is adapted dynamically in real time based on the present varying channel conditions [162].

Consider a switched diversity combining with adaptive threshold. The adaptive threshold is the dynamic threshold value based on the channel state. In particular, this adaptive threshold is achieved by the use of fuzzy logic control techniques. The technique of fuzzy logic control has made rapid progress in recent years in the field of communication [94]. The fuzzy application in wireless communication has been reported for equalization in non-linear channel [95]. K.Y.Lee [88] has given a new approach to the equalization of non-linear channels using fuzzy adaptive filters [87]. Similarly, P.Y.Chang et al [123] successfully introduced a fuzzy logic control technique for adaptive power control in a direct-sequence code-division multiple-access (DS/CDMA) cellular system. To achieve an effective fuzzy switched threshold control, both statistical analysis of mobile channels and simulations are used to refine the fuzzy IF-THEN rules. It is shown that the FLTC (fuzzy Logic Threshold Control) achieves significant improvement in the combining performance of the switched diversity while maintaining reasonable simplicity in implementation. In this system, the fuzzy logic control is used to provide an algorithm, which converts the linguistic control strategy, which is based on the characteristics of mobile radio channels, into the threshold-level control strategy for the switched diversity. This fuzzy control strategy is then converted with defuzzification into a crisp threshold control command to adjust the threshold level.

4.2 System Model of switched Diversity

Consider a two-branch switched diversity receiver given by the author Hui HUANG [67] for switched diversity combining. Let $r_1(t)$ and $r_2(t)$ be the envelopes of the signals received by the two antenna. It is assumed that the switching is done at discrete instants of time t = nT, where n is an integer, and T is the interval between switching instants. Let r_1 = r (nT) and r_2 = r(nT) denote the samples of the two signal envelopes at t = nT. The switched diversity combining is considered in this study. Figure 4.1 shows the overall schematics of two branch (r_1, r_2) switched diversity where "*Rx*" represents a receiver. In this scheme, the received signals are scanned in a sequential order, and the first signal with a power level above a certain threshold is selected. While above the threshold, the selected signal remains at the combiner's output; otherwise, a scanning process is switched to another branch. For the sake of a simple implementation, we further consider the case of switch-and-stay threshold selection. This switching process is further illustrated by assuming two independent fading signals, r_1 and r_2 coming from two antennas. Suppose the receiver is initially a state of "receiving r_1". It will "stay" at this state until r_1 goes below the threshold. When r_1 is detected to be below the threshold, the receiver switches to receiving r_2, no matter what the current signal level of r_2 is.

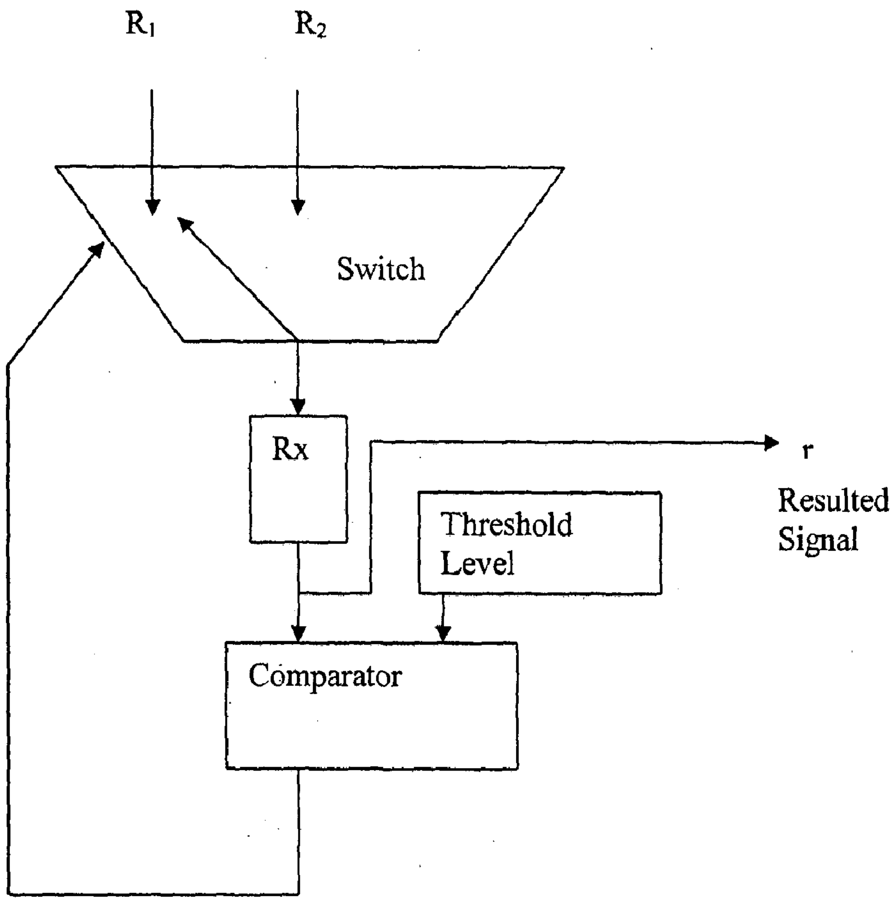


Figure 4.1 Switched Diversity with Threshold Detection

After r_2 drops below the threshold, the receiver switches to r_1, and so on. As a result, the received signal is obtained .It is noted that the threshold may be either fixed or variable. Setting its level is a task involving the knowledge of the mean signal strength in the geographical area. The performance of the switched diversity is greatly affected by the threshold level. In the proposed work, the bit error rate performance of switched diversity is evaluated by applying the fuzzy logic to the threshold level.

4.3 Bit Error Rate Performance of Switched Diversity with Threshold

The average BER of Non Coherent Frequency Shift Keying with switched diversity on two independent Rayleigh-fading channels is given by [12].

$$P_e = \frac{1}{2+\beta}(1 - e^{-\frac{\xi}{\beta}} + e^{-\xi(\frac{1}{2}+\frac{1}{\beta})}) \tag{4.1}$$

It is seen that P_e is a function of the fading parameter m, the average SNR on each branch β, and the switching threshold ξ.

4.4 The Switched Diversity Combining with Fuzzy Logic Threshold Control

It is well known, the choice of the fuzzy control rules has a substantial effect on the performance of a Fuzzy Logic Threshold Control (FLTC). Basically, the FLTC *comprises four principal components: a fuzzification interface, a fuzzy rule base,* an inference engine, and a defuzzification interface [94]. The fuzzification interface intends to convert the input values, such as the current channel state (signal strength), the channel state variation, and the current threshold, into some linguistic values, i.e., fuzzy sets. The fuzzy rule base, which comprises knowledge of the specific application and the attendant control goals, is used to define linguistic control rules and fuzzy number manipulation in an FLTC. Likewise, the inference engine is a decision-making logic mechanism of an FLTC. This concept has been applied to simulate mobile radio channel based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implications and the rules of inference in fuzzy logic. Finally, the defuzzification interface converts fuzzy control decisions into crisp value. Which are applied to adjust the threshold level of the switched diversity.

A close observation of mobile channel indicate that, if the threshold level is high, most likely the output signal of the switched diversity will be in the lower value for long time, which in turn implies that the overall system performance will be poor. In such case, the threshold level should be decreased. Similarly, if the threshold level is very low, it becomes more difficult to catch up a high level signal. Thereby, it achieves very little gain especially in the region with high signal strength. Based on these observations, consider four linguistic variables, S, ΔS, Th and ΔTh, which denote the present channel state (signal power), the variation of channel state (received signal level), the previous threshold level and the change of threshold level, respectively. The output control linguistic variable is

ΔTh, while the other three variables are used as inputs. The schematic of the switched diversity is given in Figure 4.2, which always work with normalize signal power.

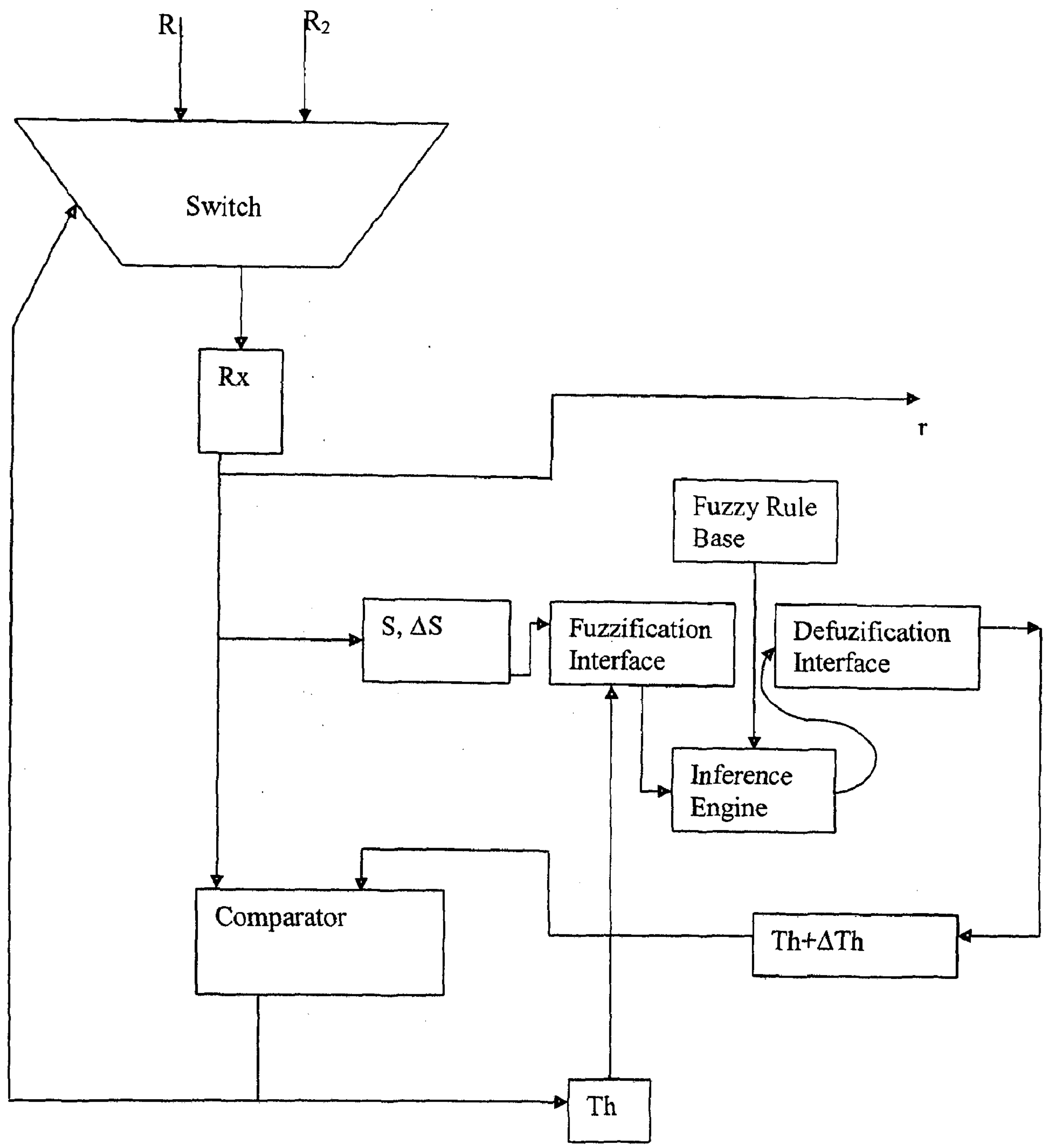


Figure 4.2 Fuzzy Threshold Switched Diversity

In this analysis, we shall determine the Fuzzy Rule Base, Inference Engine, and Defuzzification Interface elements.

4.4.1Fuzzification

The universes of discourse for S, ΔS, Th and ΔTh are assumed to be [67]

$$U_s = \{S \mid -30 \text{ dB} \leq S \leq 10 \text{ dB}\}, \quad (4.2)$$

$$U_{\Delta S} = \{S \mid -10 \text{ dB} \leq \Delta S \leq 10 \text{ dB}\}, \quad (4.3)$$

$$U_{Th} = \{Th \mid -30 \text{ dB} \leq Th \leq 10 \text{ dB}\}, \quad (4.4)$$

$$U_{\Delta Th} = \{Th \mid -10 \text{ dB} \leq \Delta Th \leq 10 \text{ dB}\}, \quad (4.5)$$

Where the bounds of the universes of discourse are determined in terms of the fading statistics of typical wireless channels. The associated fuzzy term sets are {L (Large), M (Medium), S (Small)} for S and Th, and {PL (Positive Large), PM (Positive Medium), PS (Positive Small), NL (Negative Large), NM (Negative Medium), NS (Negative Small)} for ΔS and ΔTh.

4.4.2. Fuzzy Inference

It is noted that there are 324 possible combinations of the above fuzzy terms, which generate 324 fuzzy IF-THEN rules. If all the rules are used in constructing the fuzzy system, fuzzy logic design will be very complicated, which in turn contradicts the goal of the present analysis. The experiments show that there are very few IF-THEN rules, which indeed dominate the performance of FLTC.

However, an incomplete set of fuzzy IF-THEN rules may cause an ill-defined and unstable fuzzy system, which is not desirable [125]. To overcome this problem, we have chosen the Gaussian membership functions, which cover the whole universes of discourse for each linguistic variable. The following Gausian membership functions are used [67].

$$\mu_L(S) = e^{-(S-6)2/16}; \tag{4.6}$$

$$\mu_M(S) = e^{-(S+2)2/16}; \tag{4.7}$$

$$\mu_S(S) = e^{-(S+20)2/16}; \tag{4.8}$$

$$\mu_L(Th) = e^{-(Th-10)2/16}; \tag{4.9}$$

$$\mu_M(Th) = e^{-(Th+4)2/16}; \tag{4.10}$$

$$\mu_S(Th) = e^{-(Th+22)2/16}; \tag{4.11}$$

$$\mu_{PL}(\Delta S) = e^{-(\Delta S-10)2/4}; \tag{4.12}$$

$$\mu_{NL}(\Delta S) = e^{-(\Delta S+10)2/4}; \tag{4.13}$$

$$\mu_{PM}(\Delta S) = e^{-(\Delta S-5)2/4}; \tag{4.14}$$

$$\mu_{NM}(\Delta S) = e^{-(\Delta S+5)2/4}; \tag{4.15}$$

$$\mu_{PS}(\Delta S) = e^{-(\Delta S-2)2/4}; \tag{4.16}$$

$$\mu_{NS}(\Delta S) = e^{-(\Delta S+2)2/4}; \tag{4.17}$$

$$\mu_{PL}(\Delta Th) = e^{-(\Delta Th-8)2/4}; \tag{4.18}$$

$$\mu_{NL}(\Delta Th) = e^{-(\Delta Th+8)2/4}; \tag{4.19}$$

$$\mu_{PM}(\Delta Th) = e^{-(\Delta Th-4)2/4}; \tag{4.20}$$

$$\mu_{NM}(\Delta Th) = e^{-(\Delta Th+4)2/4}; \tag{4.21}$$

$$\mu_{PS}(\Delta Th) = e^{-(\Delta Th-1)2/4}; \tag{4.22}$$

$$\mu_{NS}(\Delta Th) = e^{-(\Delta Th+1)2/4}. \tag{4.23}$$

The Analysis for selecting the most significant IF-THEN rules and determining the parameters of the above membership functions is very hard. This is because the wireless channel is always varying, which implies that it is difficult to obtain some input-output pairs such that we can use standard methods such as Gradient Descent Training or Recursive Least Squares [94] to derive the required membership functions. In present analysis, we use extensive results of experiments to verify the effects of different IF-THEN rules along with different parameters in membership functions. Eventually, we find that the following six IF-THEN rules, along with the attendant membership functions defined in [94], are shown to be dominant to the overall system performance of the FLTC. The five rules are:

If S is small, Th is large, Δ S is negative large, then ΔTh is negative large

If S is small, Th is medium, ΔS is negative medium, then ΔTh is negative medium

If S is medium, Th is large, ΔS is negative medium, then ΔTh is negative medium

If S is medium, Th is small, then ΔTh is positive small

If S is large, Th is small, then ΔTh is positive medium.

If S is large, Th is medium, ΔS is positive medium, then ΔTh is negative small

4.4.3. Defuzzification

The defuzzification is implemented using the product inference engine and the center average defuzzifier [94], we obtain a very simple fuzzy adaptive threshold control ΔTh_{fuzz}, which is given by-

$$\Delta Th_{fuzz} = \frac{-8Y_1 - 4Y_2 - 4Y_3 + 4Y_4 + Y_5 + Y_6}{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6} \qquad (4.24)$$

Where $Y_1 = \mu_S(S) \cdot \mu_L(\Delta Th) \cdot \mu_{NL}(\Delta S)$, $Y_2 = \mu_S(S) \cdot \mu_M(\Delta Th) \cdot \mu_{NM}(\Delta S)$, $Y_3 = \mu_M(S) \cdot \mu_L(\Delta Th) \cdot \mu_{NM}(\Delta S)$, $Y4 = \mu_L(S) \cdot \mu_S(\Delta Th)$, $Y_5 = \mu_M(S) \cdot \mu_S(Th)$. And $Y_6 = \mu_L(S) \cdot \mu_M(Th)$. $\mu_{NS}(\Delta S)$.. The threshold control in above equation is implemented in the defuzzification Interface in Figure 4.2.

4.5 Results & Discussion

The probability of bit error rate has been investigated and the probability of bit error rate have been analyzed without diversity and with diversity for different value of the threshold. The Figure 4.3 shows the probability of bit error rate versus signal to noise ratio without the diversity. These result shows that the probability of bit error rate decreases as the signal to noise ratio increases. The probability of error high in this case because of single receiving path and no diversity is used. The Figure 4.4 shows the probability of bit error rate for lower threshold value i.e. Th =-4. The Probability of bit error rate decreases with increase in signal to noise ratio but this value is less than the case of without diversity. This value less because of the two branch diversity and the switching take place at the threshold value. The two branch diversity give good results because of any one of them may have good signal strength. Further, figure 4.5 shows the probability of bit error rate with signal to noise ratio for increased value of the threshold. The probability of bit error rate improved due to higher value of signal to noise ratio at higher threshold value. Next is the figure 4.6 which shows the probability of error with signal to noise ratio by applying fuzzy logic at the threshold value. The probability of bit error rate improves further because of adaptive nature of threshold value. Thus fuzzy logic application has improved bit error rate substantially.

In this work, we have analyzed an effective fuzzy logic control switched diversity (FLTC) scheme, which can be considered to be used in mobile units. To achieve a simplified design of FLTC, which is a key element of the FLTC, the efforts have been made in selecting the most significant fuzzy IF-THEN rules and determining the parameters of the associated membership functions. Eventually, we find that there are in fact only six IF-THEN rules are considered for analysis and the resulted fuzzy threshold control has a very simple form. Results show that the proposed FLTC can achieve a significant improvement in system performance in terms of both the diversity gain and BER over various channel conditions.

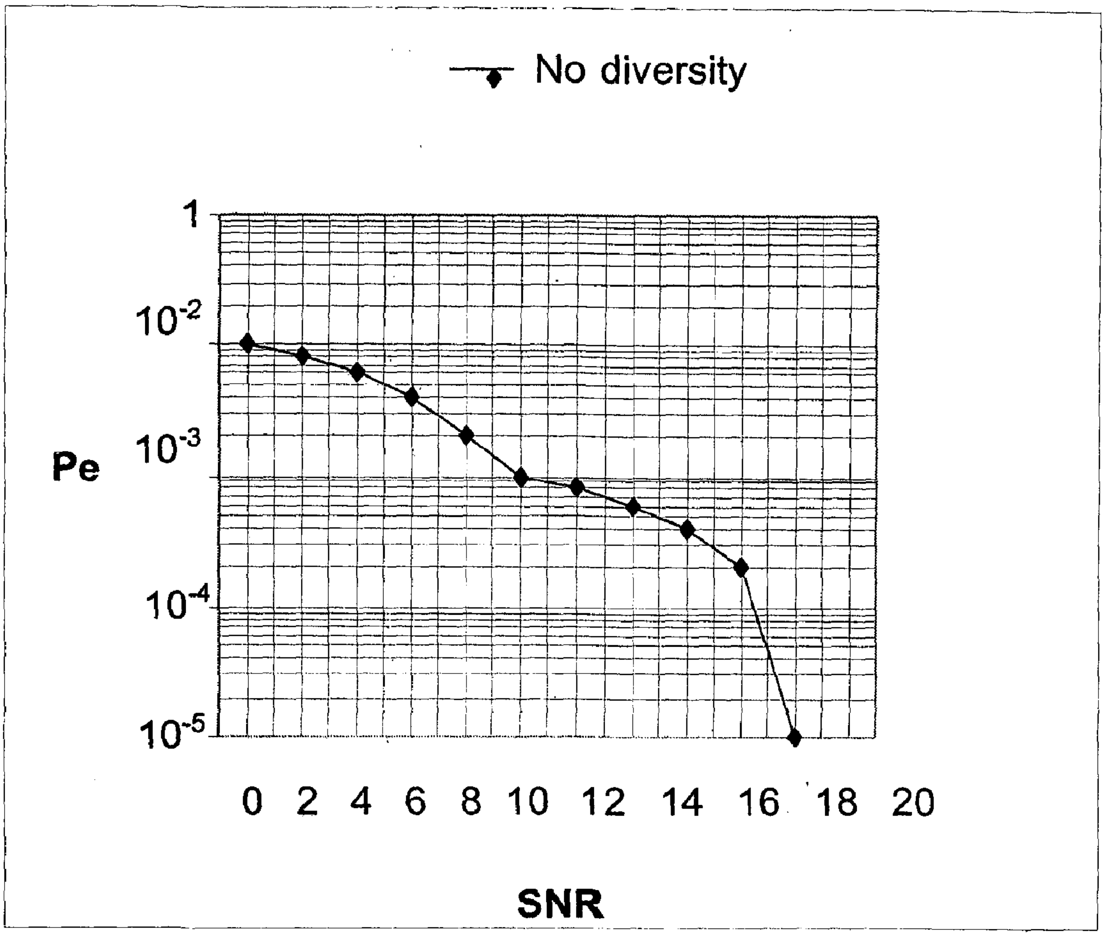


Figure 4.3 Probability of Error Rate (No Diversity)

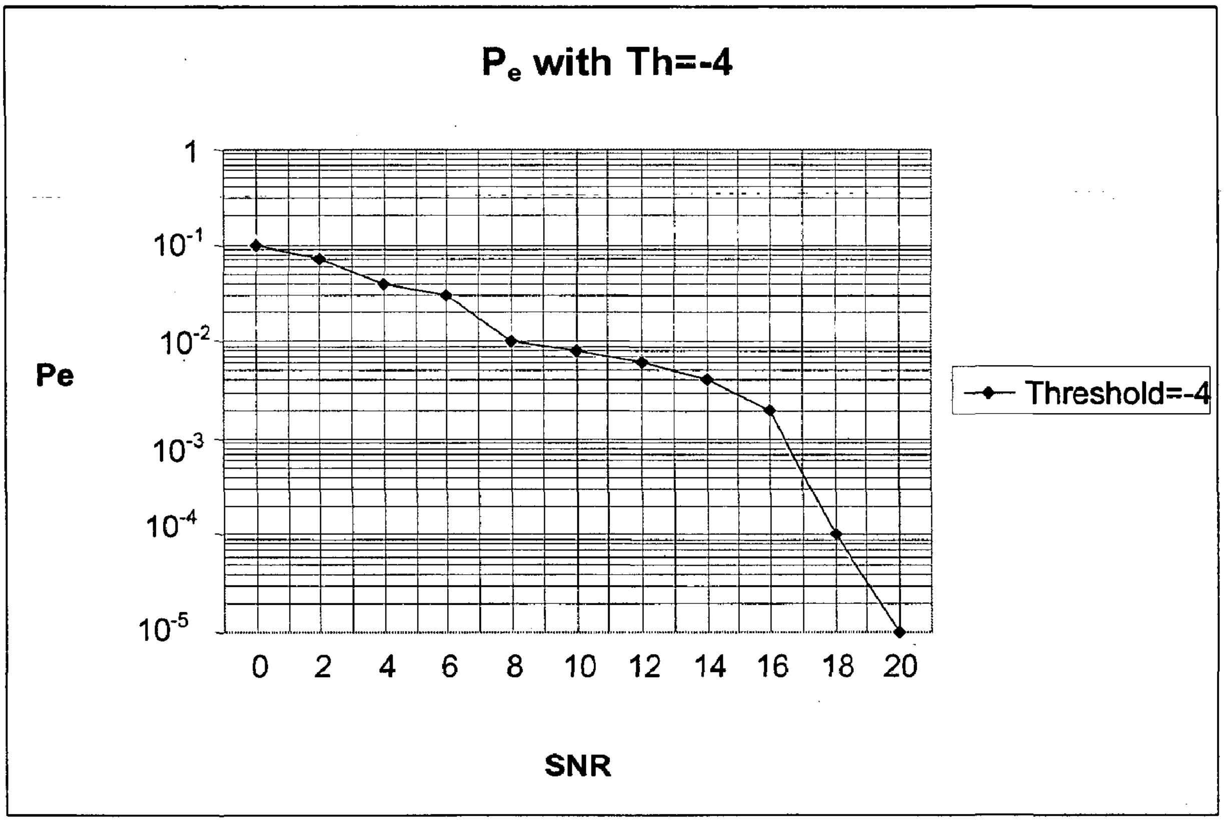


Figure 4.4 Probability of Error Rate (Th=-4)

Chapter 5

Capacity Analysis of Soft Handoff in CDMA System with Macro Diversity

5.1 Introduction

5.2 Soft Handoff & Macro Diversity in CDMA

5.3 Factor influencing the Capacity of CDMA

5.3.1 Path loss

5.3.2 Voice activity factor

5.3.3 Interference distribution factor

5.4 Capacity Analysis of Soft Handoff in CDMA

5.4.1 Analysis without Macro Diversity

5.4.2 Analysis with Macro Diversity

5.5 Results & Discussion

Chapter 5

Capacity Analysis of Soft Handoff in CDMA System with Macro Diversity

5.1 Introduction

The soft handoff is a process on transferring the on going call from one radio resource to another radio resource without any interruption. The connection of ongoing call does not break in the soft handoff in the transfer process. Rather, mobile unit looks next base station for possible new connection without breaking the old connection. This transfer of call takes place, when the mobile unit moves far away from old base station and approach toward new base station. At the far away distance from old base station, the signal to noise power at the mobile unit becomes poorer and the service quality get degrade. At this far away distance mobile unit may see the another new base station, which may provide the better signal to noise ratio of the same signal via mobile switching center (MSC). Thus the mobile unit may get the same signal from the two different base stations simultaneously. This area in which mobile unit receive the signals from the two different base stations is known as soft handoff region. This transfer of call from one base station to another base station is called the soft handoff.

During soft handoff process more than one base station take part in the communication process and the signals are combined at the mobile unit. This form of diversity is known as base station diversity or macro diversity [14]. This is the power full technique to combat the shadowing effect in cellular mobile radio system and improve the transmission performance at the cell boundaries. In CDMA system soft handoff and macro diversity can be efficiently applied for adjacent radio cells using the same radio frequency channels.

The signal sent out by the mobile station is received simultaneously by two or more spatially separated base stations on uplink. The Diversity combining take place at a common node in the hierarchically organized base station subsystem and can be implemented by frame-by-frame selection combining or even more powerful, by maximum ratio combining using soft decoding information provided by the base station receivers. The capacity of CDMA network depends on the signal to noise ratio. The signal to noise ratio is affected by the voice activity factor. The effect of the voice activity factor on the system capacity in the soft handoff region has been analyzed.

5.2 Soft handoff for CDMA Network

The soft handoff in cellular code-division multiple-access (CDMA) systems is a technique whereby mobiles near cell boundaries communicate the same transmitted signals to more than one base station (BS) within their vicinity

[93,35,124]. Soft handoff is important because it provides enhanced communication quality and a smoother transition compared to the conventional hard handoff. On the reverse-link, signals transmitted by mobiles in the handoff area may reach all the nearby BS's, even though the signals are not intended for them and the mobile signals appear as interference in these nearby cells. By putting more matched filters in the receiver, BS's can receive signals from mobiles in the nearby soft- handoff areas. Notice that no extra channels are required to accomplish soft handoffs on the reverse links. Soft handoff provides macro diversity, which is due to more than one BS being involved in the communications. The signal-to-interference ratio (SIR) is improved by combining the signals from the different BS's, and this, in turn, increases reverse-link quality and extends cell coverage [13,14]. As there are at least two BS's involved in the soft-handoff process, where each BS supports a forward-link channel to the mobile, the number of available channels on the forward link decreases as the number of mobiles in soft handoff increases. This factor has a effect effect on the system capacity.

5.3 Factor influencing the Capacity of CDMA

The following factors affect the capacity of CDMA network.

5.3.1 Path loss

The path loss varies with the distance between the fixed base station and the moving mobile station. In free space it follows the inverse square power-law which means that the received power will decrease according to the square of the communication link distance d. For other cases, then simplest empirical model of the path loss, μ, is

$$\mu(d) = k.d^{\beta} \tag{5.1}$$

where β is the path loss exponent ranging from 2 in free space to 4 in a dense urban area. If in our model we use β = 4 and the constant k = 1, we can rewrite our path loss model equation (5.1) in dB as

$$\mu(d) = 40 \log d \text{ dB} \tag{5.2}$$

The term excess path loss for equation (5.1) is used, since the attenuation the free space attenuation.

5.3.2 Voice Activity Factor (VAF)

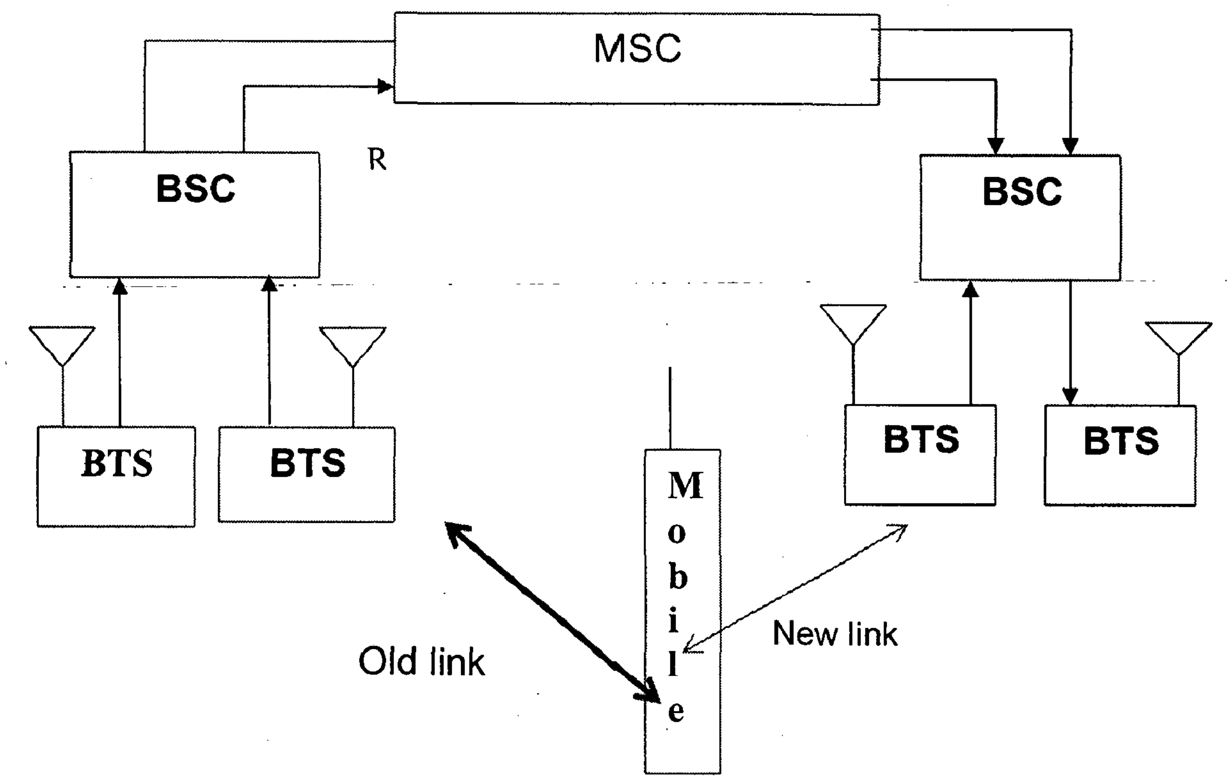
Voice activity factor denotes activity of speech in terms of time of the speaker. The speaker is silent (no voice) most of the time. The fraction of time for which the speech of the speaker is active (voice) is called voice activity factor. One advantage of CDMA is that it can readily exploit the nature of human conversation to increase system capacity. It can suppress the transmission from a user when there is no voice present or in other words transmission is activated only when the voice is present. Most existing digital vocoders can monitor user voice activity and studies show that typical speech is active only 35% to 40% of the time [46]. Exploitation of this situation introduces less interference to the system since it reduces the average transmit power during silence periods and hence increases the system capacity. Typical values for the voice activity factor (ν) range from 0.35 to 0.4.

5.3.3 The Interference Distribution Factor

The capacity of CDMA network is affected by the interference of other users [46]. The interference in CDMA is high due to similar frequency spectrum of all the mobile units. The interference at a base station is highly dependent on the mobile station location and the position of the base station. There are two scenarios for interference distribution namely multicell and single cell network. The inter cell interference factor f can be evaluated by the serving cell and power received from mobiles in other cells. The interference factor is low in the following conditions: (i) Serving cell radius is small (ii) path loss slope has a higher value (iii) The standard deviation of path loss is small. The interference factor [92] for two way handoff and three way handoff is given in Table5.1.

Table 5.1 Intercell interference factor (f)

$\sigma(dB)$	Interference	Factor (f)
	Two way soft handoff	Three way soft handoff
0	0.44	0.44
2	0.43	0.43
4	0.47	0.45
6	0.56	0.49
8	0.77	0.57
10	1.28	0.75
12	2.62	1.17



R- handoff request sent to the old cell

Energy measurements are made at the mobile

Figure 5.1 Soft Handoff Architecture

5.4 Capacity Analysis of Soft Handoff in CDMA

The capacity of the CDMA communication network depends on the diversity technique used. The capacity gain of CDMA communication network can be defined by the comparison of network capacity with macro diversity and without macro diversity. The macro diversity provides soft handoff by combining the signals transmitted by the involved base station's [124,14]. When the signal from the two base stations are combined, the probability that the signals from the base station's are all simultaneously subjected to deep shadowing is much smaller than that from a single base station. The gain in SIR can be obtained by combining the received signals from these BS's. This gain in SIR, in turn, increases the system capacity. By comparing the capacity with macro diversity to that without macro diversity, the capacity gain of the CDMA system due to soft-handoff diversity can be determined [14]. It is proposed to study the capacity of CDMA communication system without diversity and with diversity and to analyze the effect of voice activity factor and interference factor on the capacity of CDMA communication network.

5.4.1 Capacity Without Macro diversity:

Consider a CDMA forward link system with coherent demodulation, which is achieved by sending a CDMA pilot with all the traffic channels [46,15]. Suppose no diversity technique is applied, i.e., signals are not combined at the mobile unit. The mobiles near the BS's have a higher SIR than those mobiles near the boundary, the SIR on the forward link is dependent on the mobile's location. Consequently, the forward-link capacity is limited by the SIR, when mobiles are located at the boundary.

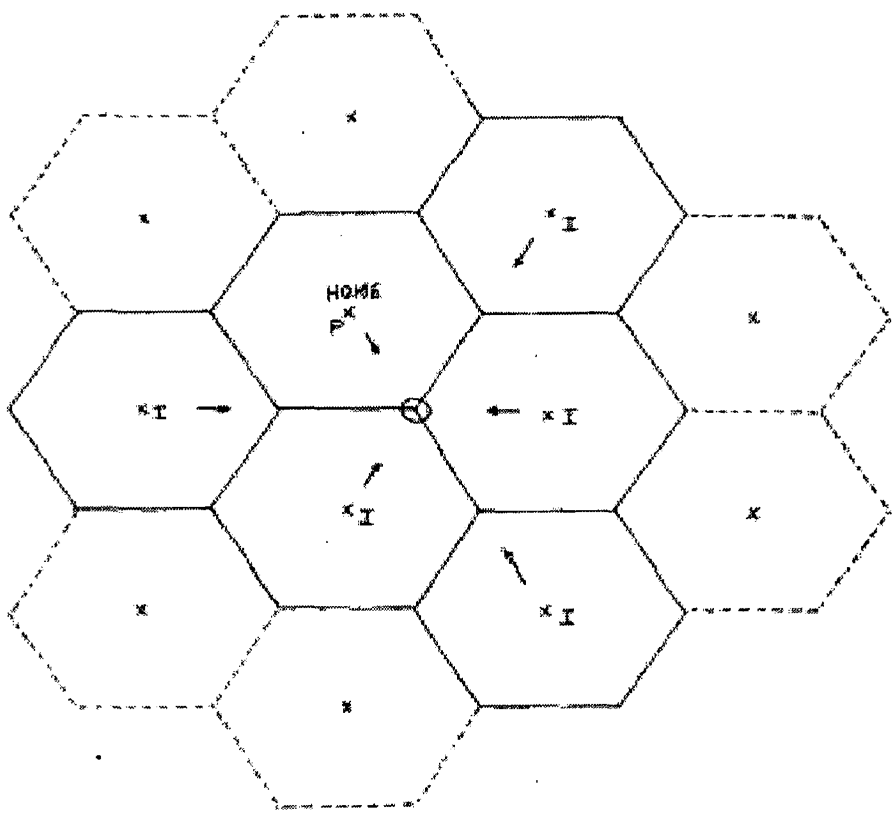


Figure 5.2 CDMA system and its interference

Consider the twelve-cell scenario in the figure 5.2, which has the hexagonal cell in the architecture. Let us consider M channels in each cell. The radio capacity is calculated from the carrier to interference ratio(C/I). The C/I received by the mobile at a distance r from the base station of a CDMA cell shown in figure 5.2 is based on nine interfering cells, given as follows [93]:

$$(C/I)_s = \frac{\alpha . r^{-4}}{\alpha (M-1) R^{-4} \mu + \alpha .2M.R^{-4} \mu + \alpha .3M.(2R)^{-4} \mu + \alpha .6M.(2.633.R)^{-4} \mu + \eta} \tag{5.3}$$

Where r =Distance of MS from BS M= Number of channels

R =Cell radius, η = noise power

The bit energy to noise ratio can be calculated from (C/I) by the following relation

$$\frac{C}{I} = \left(\frac{E_b}{I_0}\right)\left(\frac{R_b}{B}\right) \tag{5.4}$$

Where R_b = data rate

B = bandwidth

The capacity of CDMA system in terms of the numbers of users are given by

$$M_{max} = G_p \cdot \left[\frac{\eta_c}{\left(E_b / I_0 \right) . v_f . (1+f)} \right] \tag{5.5}$$

Where G_p = Processing gain

η_c= power control factor

E_b/I_0= bit energy to interference ratio

v_f= voice activity factor

f= interference factor

5.4.2 Capacity With Macro diversity:

The SIR of the mobiles within the soft-handoff zone can be improved by combining the received signals from the BS's.

$$\left(\frac{E_b}{I_0}\right)_0 = \left(\frac{E_b}{I_0}\right)_1 + \left(\frac{E_b}{I_0}\right)_2 \tag{5.6}$$

Therefore, the capacity can be increased in proportion to the increase in SIR. The mobile receiver block diagram is shown in figure 5.3, in which matched filter are used to detect the signals coming from the neighboring BS's. After demodulating with the carrier, which is provided by the pilot from its own BS, the received signals are matched with their corresponding spreading codes. The outputs of the matched filters are co phased and combined. It is also called maximum ratio combiner.

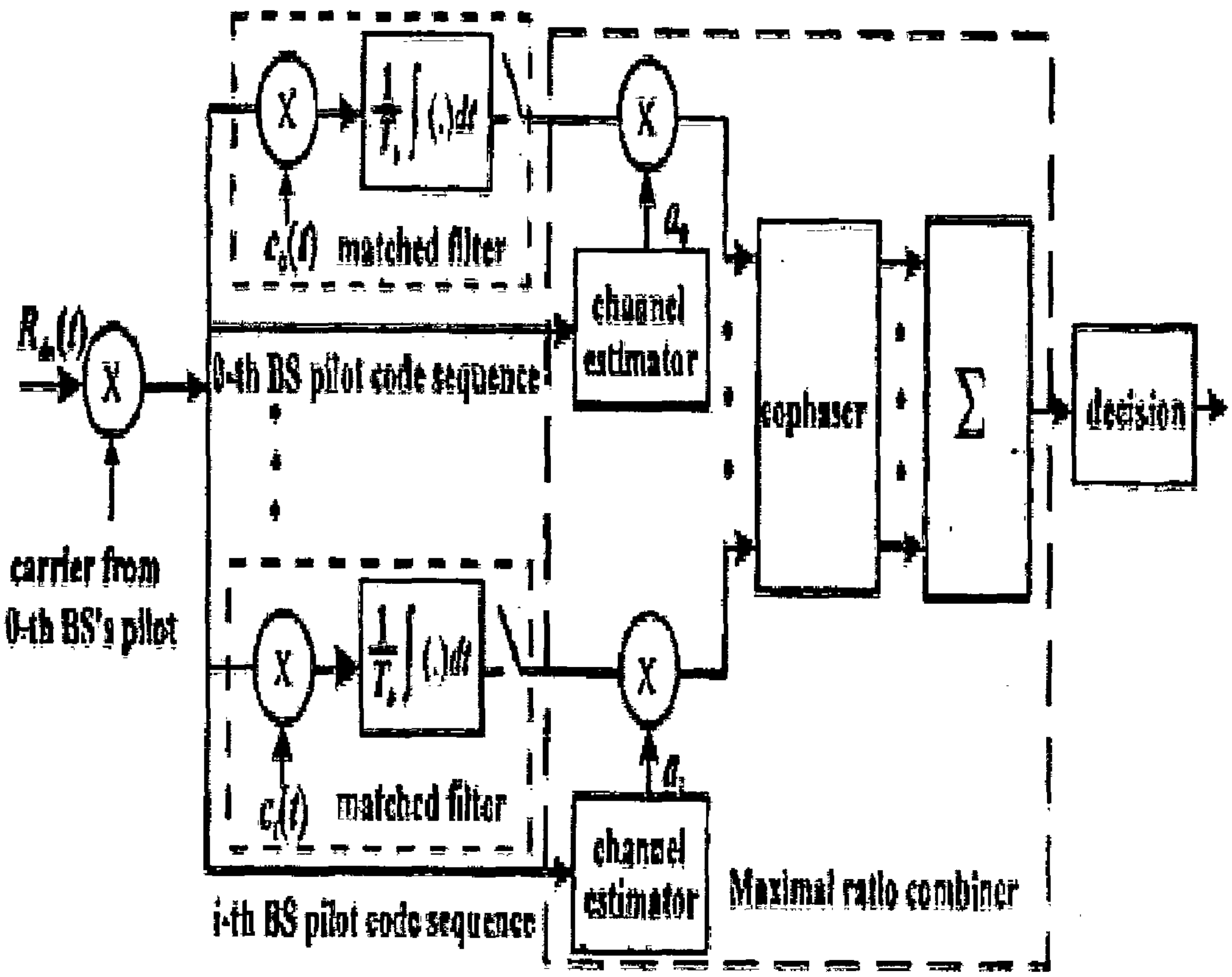


Figure 5.3 Mobile Receiver Block Diagram [77]

The channel attenuation is estimated from the CDMA pilot signal, and maximal ratio combining is performed by weighting the amplitudes of the signals according to their channel attenuation [77,164]. The weighted signal amplitudes are co phased and summed together to give maximal amplitude, where polarit determines the logical value of the regenerated bit.

5.5 Results & Discussion

For the analysis of capacity of CDMA system, we have assume a processing gain of 21 dB (127 chips per information bit) and a signal to noise ratio of 20 dB, the capacity in terms of the maximum number of users per cell for different values of normalized distance in the soft handoff zone has been calculated. We have considered the nine co channel interfering cells shown in fig. 5.2, the curves of the capacity of the forward-link system for a VAF of 3/8 and 1/2 are shown in fig.5.4 and fig.5.5. The figure 5.4 shows the capacity without macro diversity for different values of voice activity factor. The capacity is a function of the voice activity factor. The capacity is higher for the lower value of the voice activity factor. For example, the voice activity factor 3/8, the capacity is higher as compared to the voice activity factor 1/2.

Similarly, figure 5.5 shows the capacity with macro diversity for different values of voice activity factor. Again, the capacity is higher for lower value of the voice activity factor. The voice activity factor 3/8, the capacity is higher as compared to the voice activity factor 1/2. It is noted that the capacity for mobiles in the soft-handoff zone is much higher than that for mobiles in no handoff zone, hence, the capacity becomes limited by mobiles at the boundaries. The capacity gain on the forward link is the capacity difference between the capacity for mobiles at r =R and R_h=0.84R. The capacity for mobiles at r = R is 43 and 32 users per cell for a VAF of 3/8 and 1/2, respectively, while the capacity for mobiles at R_h= 0.80 R is 46 and 34 users per cell for VAF's of 3/8 and 1/2, respectively.

Figure5.6 shows the effect of the interference on the capacity of CDMA system without diversity. It is seen from this graph that the capacity of the CDMA system decrease with increase interference. Also, figure 5.7 shows the capacity of CDMA system with diversity using interference factor of value of 1.5. This graph shows that the capacity decreases with increase in interference in the CDMA system.

Consequently, the capacity gain due to macro diversity is three and two users per cell, which corresponds to a gain of 7.0% and 6.1% for VAF's of 3/8 and 1/2, respectively. As the system capacity is limited by R_h = 0.84 R, the excess capacity due to macro diversity becomes an increase in SIR for mobiles in soft handoff.

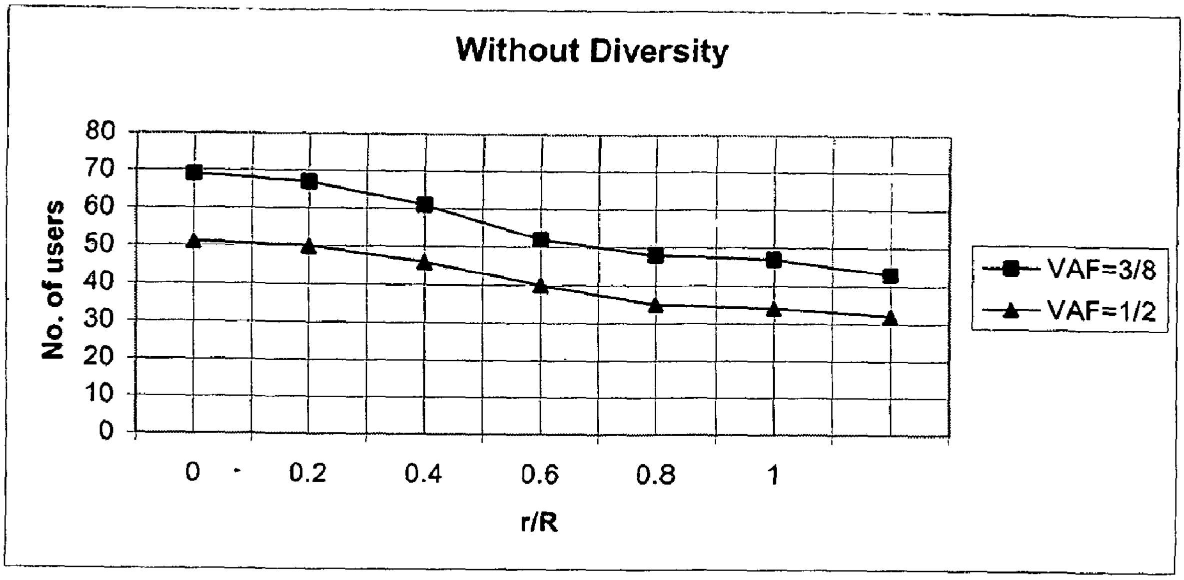


Figure 5.4 Capacity versus r/R , No diversity

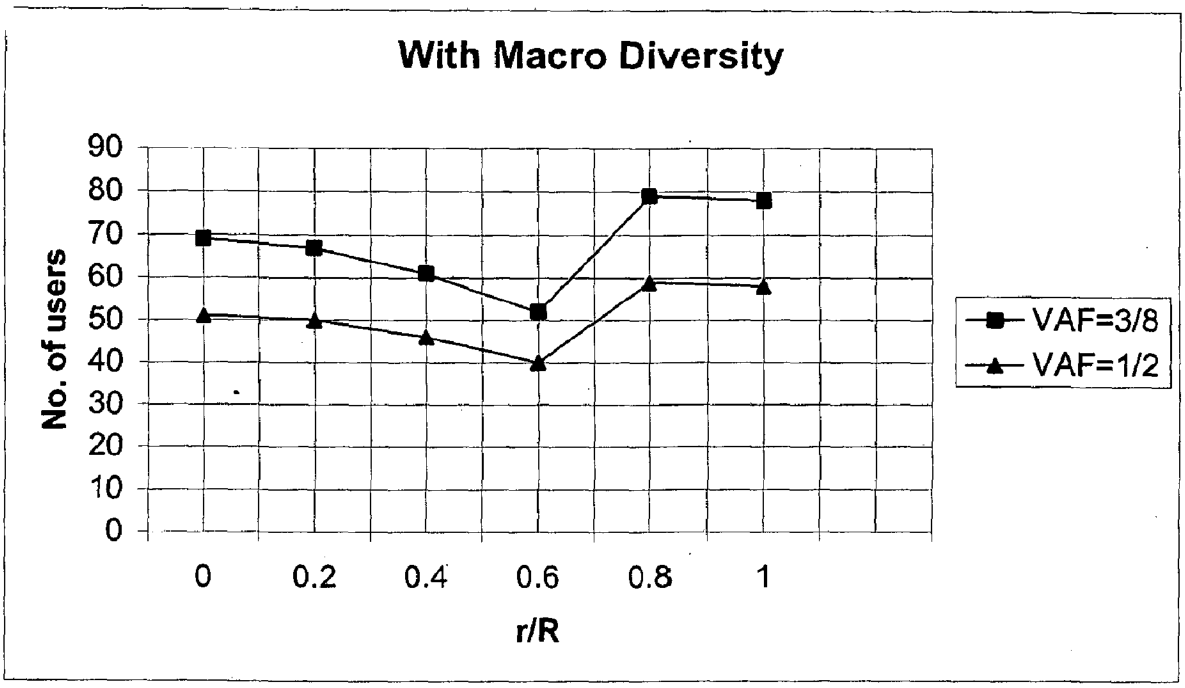


Figure 5.5 Capacity versus r/R ,Macro diversity

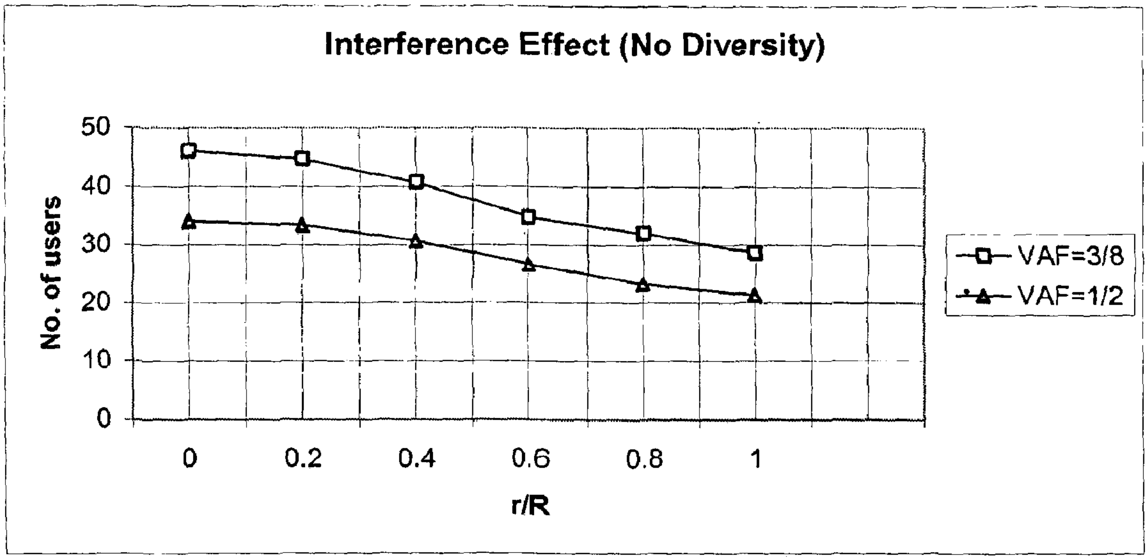


Figure 5.6 Capacity versus r/R with f=1.5, No diversity

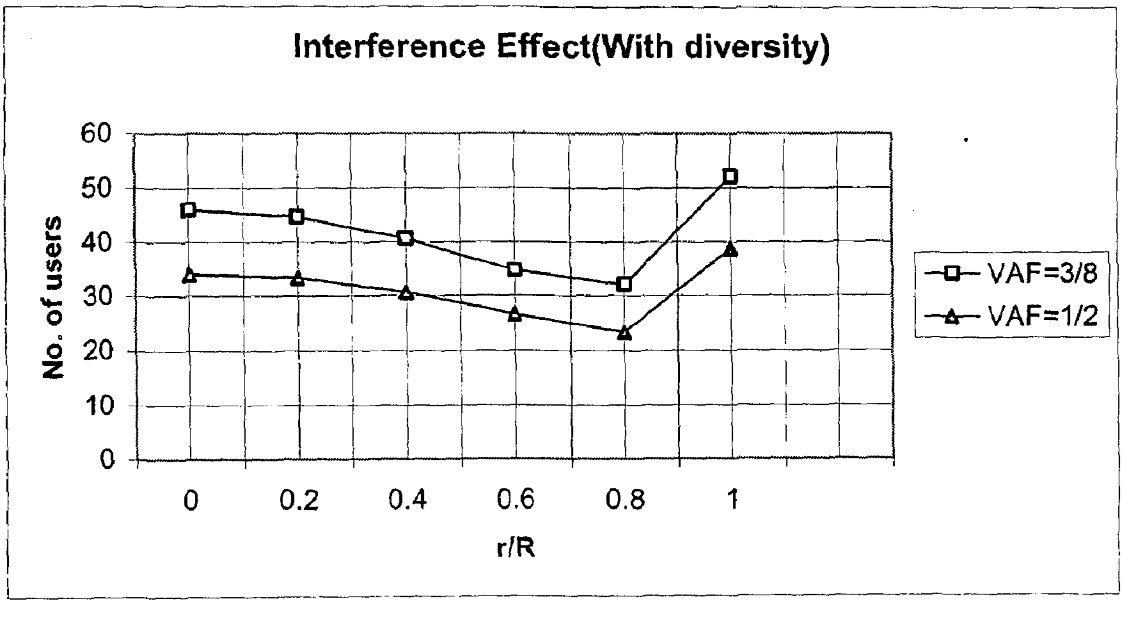


Figure 5.7 Capacity versus r/R with f=1.5, with diversity

CHAPTER 6

Performance Analysis of Soft Handoff Algorithm in CDMA

6.1 Introduction

6.2 Quality-of-Service (QoS) for Soft Handoff in CDMA

6.3 Review on Soft Handoff in CDMA

6.4 Overview Of IS-95A AND IS-95B/CDMA2000 Soft Handoff System

6.5 Fuzzy Inference System-Soft Handoff (FIS SHO)

6.6 Simulation & Performance Analysis

6.7 Results & Discussion

Chapter 6

Performance Analysis of Soft Handoff Algorithm in CDMA

6.1 Introduction

The soft handoff in CDMA is a procedure to transfer the ongoing call from one base station to another without any interruption of the ongoing call. The soft handoff is based on the make before break strategy. There is no change in the frequency range for making connection on the next coming cell. The soft handoff decision depends on the value of parameters like signal strength and signal to noise ratio, bit error rate, blocking probability etc. The soft handoff algorithms start handover process at the threshold value of the parameters. The soft handoff threshold parameters can be fixed or adjusted dynamically [138]. The fixed thresholds have poor performance as compared to the dynamically adjusted threshold handoff algorithm. The performance of soft handoff algorithm increases at the increased threshold at high traffic loads in order to release the traffic channel for supporting more carried traffic [17]. The performance decreases at the decreased thresholds at low traffic loads in order to give high quality of traffic channel [17]. The Performance of soft handoff algorithm also depend on the number of input parameters like, the number of remaining channels of each base station and number of active pilots in active set of each mobile. The output of the soft handoff algorithm is adjusted threshold value. Based on this adjusted value of threshold parameter, the performance of the IS-95 and IS-95 B/cdma2000 soft handoff algorithms reported by [17]. The performance of IS-95 and IS-95B/cdma2000 soft handoff at high traffic loads and at lower soft handoff threshold at the acceptable quality of traffic channel has also been reported with the wider soft handoff threshold value of algorithm. We have introduced an additional input E_b/I_0, in the algorithm proposed by B.Homnan [27]. A three variable fuzzy inference system is proposed and the analysis is carried by call blocking probability. The effect of this parameter on the algorithm is examined at high carried traffic load. Also the adaptive soft handoff threshold effect has been analysed at the blocking probability for the acceptable quality of traffic channels.

6.2 Quality-of-Service (QoS) for Soft Handoff in CDMA

The quality of service parameters are the indicators of the quality of parameters of ongoing call and reflect the ability of the network to carry the ongoing call. The QoS parameters is divided into two category. (i) The network point of view (ii) Call quality point of view.

Trunk resource efficiency (TRE) and the new call blocking probability are the QoS parameters from network point of view. Call quality is the QoS parameters from the ongoing call point of view. The call quality parameters are signal to noise ratio (SNR), signal to interference ratio (SIR), bit energy to noise ratio (E_b/No), Bit error rate.

The outage probability depends on the forward link's average energy per bit to the interference plus noise power spectral density ratio and the outage probability are used to evaluate the system performance. The adapted add threshold (T_Up) and the adapted drop threshold (T_Down) in soft handoff (SHO) process are used to control Call quality. The soft handoff is a diversity handoff, because each MS in soft handoff area uses two or more traffic channels from different BSs simultaneously. The QoS parameters, signal to noise ratio is combined by the diversity combiner to enhance the signal strength.

6.3 Review on Soft Handoff in CDMA

Many SHO algorithms have been reported in literature for better system performance at high traffic load and adjusted QoS parameters[165,68,25,138,17,170,171,26,27] . Chen et al [165] considered adaptive traffic load shedding (ATLS) to reduce at high traffic load. This scheme allows heavily loaded BSs to dynamically shrink their coverage areas, while less loaded adjacent BSs increase their coverage areas to support extra traffic by transmitting higher power to the MSs that will handoff from the adjacent heavily loaded cells. The disadvantage is that a BS has to request the adjacent BSs to increase their coverage area before it can reduce its coverage area. However, BSs cannot increase or reduce their pilot strength independently. Jeon *et al.* [68] proposed a new channel-assignment scheme for reducing in call blocking probability in cellular system. Jeon's algorithm had done by increasing the value of threshold, when the traffic channel is not available, to force an MS or MSs out of the SHO process. The disadvantage of this method is that the BS must calculate the mean and variance of the total received signal power. This is not practical in the real system. Moreover, Jeon et al has considered using only two fixed values of threshold. Therefore, it was quite a coarse adaptation of threshold in following a wide range of offered traffic load. It is very difficult for the BSs to rapidly react to the variations of traffic load [68]. Worley and Takawira [25] stated to have upper and lower thresholds of MS transmitted power in order to define conditions in deciding when to start process of handoff. Generally, a BS has no information about the MS transmitted power so, in this method, an MS must send this information to a BS to compare it with the defined thresholds. Hwang *et al.* [138] had allowed the handoff thresholds to vary dynamically according to the traffic density in each cell. Only two fixed values of each threshold are assigned. The comparison of the system performance with the conventional IS-95A SHO [165] has been observed only for two fixed threshold. Thus, it was not sufficient in comparing all aspects of the system performance. It is reported that the IS-95B/cdma2000 Soft Hand off algorithm is partly different from that considered in [17]. In addition, Soft Handoff algorithms are based on statistical modeling with Poisson arrival process and exponential holding time process, while Cheda's et al [17] discussed the simulations are not based on poission arrival process and exponential holding time process [17]. Therefore, a better view of QoS-controlling Soft Hand off parameters is to apply fuzzy logic to adjust parameters dynamically. Y. Kinoshita *et al.* [170] had applied fuzzy logic theory in handoff process, they applied fuzzy inference for learning to know the cell boundary [170]. K. Oku [171] et al has considered to increase the number of inference rules for softer decision, and he emphasized hard handoff in the indoor area.

Homnan and Benjapolakul [26] proposed fuzzy inference system (FIS) by using the signal strength MS receives and the distance between MS and BS for inputs while output is a defined value for handoff decision. Homnan et al.[27] added a concept of dynamic handoff thresholds by using Fuzzy Inference System -based Soft Hand off (FIS SHO) [26,27,172,148], which consists of inference rules of human-oriented information. Moreover, the number of the remaining channels and the number of pilots in active set were introduced to be used as the FIS SHO inputs by Homnan et al. This method is called as "the two-input FIS SHO" method and is different from those reported in [170,171,26]. This FIS SHO method support more users than the conventional SHOs (IS-95A SHO and IS-95B/cdma2000 SHO). This FIS-SHO gives higher call quality with the IS-95 system. The three inputs FIS SHO is proposed to consider the tradeoff call quality and to solve the problem that call quality is not guaranteed in the previous method of FIS SHO [27,172,148]. Therefore, a proper input, Eb/Io, is introduced into the algorithm proposed by Homnan et al [27] to solve this problem. The motivation to study this method is based on the following considerations. The simple step control (SSC) is used to control a parameter by letting that parameter swing around the threshold. The advantage of SSC is its low complexity, because it only compares the controlled parameter with the required value in order to give a new appropriate controlled value. When QoS is controlled, it means that the system or SHO performance can be controlled as required. The two-input FIS SHO proposed by Homnan et al is evaluated by adding another input "Eb/Io " to make the three-input FIS SHO (controlling SHO based on FIS), and is implemented at the BS controller.

6.4 Overview Of IS-95A And IS-95B/CDMA2000 SHOS

A mobile station (MS) in CDMA has four channel sets: the active set (AS), the candidate set (CS), the neighbor set (NS), and the remaining set (RS). The various step of IS-95A soft handoff process reported in [123] are explained in brief below [123].

i) When the received pilot signal strength at the mobile station exceed T_Up that of a pilot in the neighbor set (NS), the mobile station (MS) sends a pilot strength-measurement message (PSMM) to its BS and transfers that pilot to its candidate set (CS).

ii) The BS sends an extended handoff direction message (EHDM), a general handoff-direction message (GHDM), or a universal handoff direction message (UHDM) to the MS in order to proceed to the next step.

iii) The MS transfers the pilot to the active set and sends a handoff completion message (HCM) to the BS.

iv) When the pilot strength of a pilot in the active set drops below, the MS sends a pilot strength measurement message (PSMM) to the BS.

v) The BS receives the pilot strength measurement message (PSMM).

vi) The BS sends an extended handoff direction message (EHDM), a generalized handoff direction message (GHDM), or a universal handoff direction message (UHDM) to the MS.

vii) The MS transfers the pilot from the AS to the NS and sends a handoff completion message (HCM) to the BS.

6.5 Fuzzy Inference System-Soft handoff (FIS SHO)

There are three important subprocedures in the FIS SHO algorithm fuzzification, fuzzy inference, and defuzzification. The inputs of the previous FIS SHO algorithm proposed by Homnan et a l[27] considered number of base station (no_{BS}) of the MS and remaining channel (CH_{rm}) of the serving BS. The outputs of the algorithm are a T_Down and a T_Up , where T_UP=T_Down+2 db .The inputs and outputs of the FIS SHO control plant of each MS is considered in forms of linguistic variables and fuzzy sets are given in table 6.1.

Table 6.1 Linguistic Variables and fuzzy set (two input FIS)

Linguistic Variable	Fuzzy Sets
no_{BS}	$\in$ {Low, Medium, High}
CH_{rm}	$\in$ {Low, Medium, High}
T_Down	$\in$ {Low, Medium, High}

Obviously, the SHO thresholds, which depends on the instantaneous traffic load in each BS, can be adapted by using as one of the three inputs to FIS SHO.

In our analysis, the additional input $\frac{E_b}{I_0}$ is added to the two inputs FIS SHO to analyze the system performance. The $\frac{E_b}{I_0}$ is added to linguistic variable in fuzzy set as shown in figure 6.1The membership functions are added into the database of the two inputs FIS-SHO. Table 6.2 shows fuzzy set for three input FIS SHO.

Table 6.2 Linguistic Variables and fuzzy set (Three I/P FIS)

Linguistic Variable	Fuzzy Sets
no_{BS}	∈{Low, Medium, High}
CH_{rm}	∈{Low, Medium, High}
$\frac{E_b}{I_0}$	∈{Low, Medium, High}
T_Down	∈{Low, Medium, High}

i) Fuzzification: The fuzzification is a procedure to convert crisp input into the fuzzy input. The crisp inputs are changed to be fuzzy inputs in the fuzzification process by the membership functions (MFs) (Fig. 6.2), which are in the databases of each mobile station, as shown in figure 6.1. The triangular MF is used because its parameters' values are easier to be designed. Because the minimum no_{BS} of an active MS is 1, The "1" is assigned to one corner of the trapezoidal MF termed "Low" and one corner of the triangular MF termed

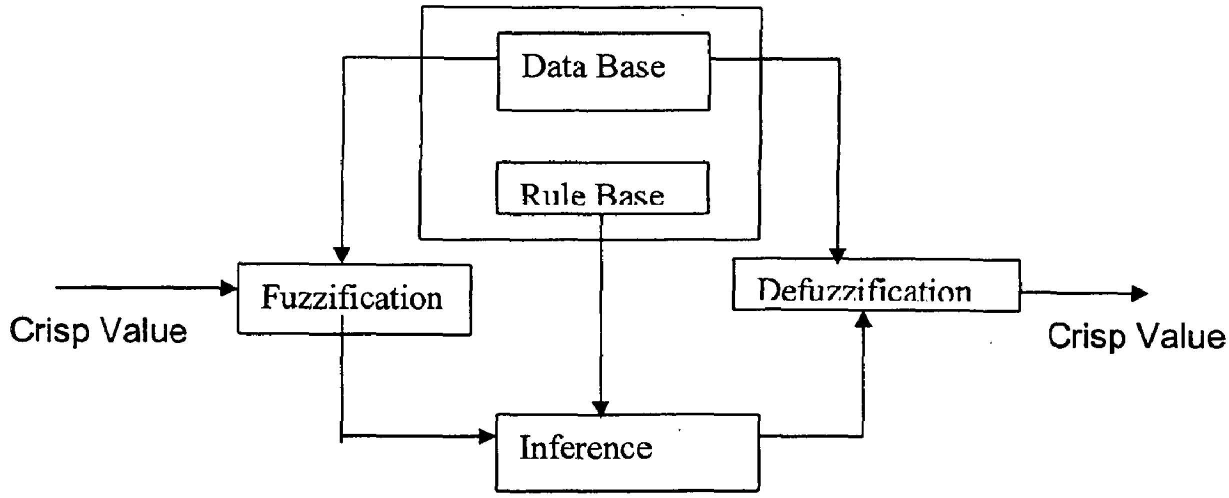


Figure 6.1. FIS SHO (Three input FIS SHO) control plant of each Mobile Station

"Medium." Because 2 is normally required for SHO, "2" is assigned to one corner of the triangular MF termed "Medium" . Because 3 indicates that an MS tends to use excessive traffic channels, "3" is assigned to one corner of the triangular MF termed "Medium" and one corner of the trapezoidal MF termed "High." The maximum no_{BS} is 6, thus, the x –coordinate of no_{BS} is limited to "6". Consider the membership function for CH_{rm}, "5" is approximated from six neighboring cells plus the serving cell itself (equals 7 in the standard seven-cell model in mobile communication systems [16,41] is assigned to one corner of the trapezoidal MF termed "Low" and one corner of the triangular MF termed "Medium," as shown in figure 6.3. Note that "7" and its multiples are not used to define the corner values of the MFs, but "5" and its multiples are used instead because it is easier to design. Thus, "5" is used as the base value of the number of the available channels.

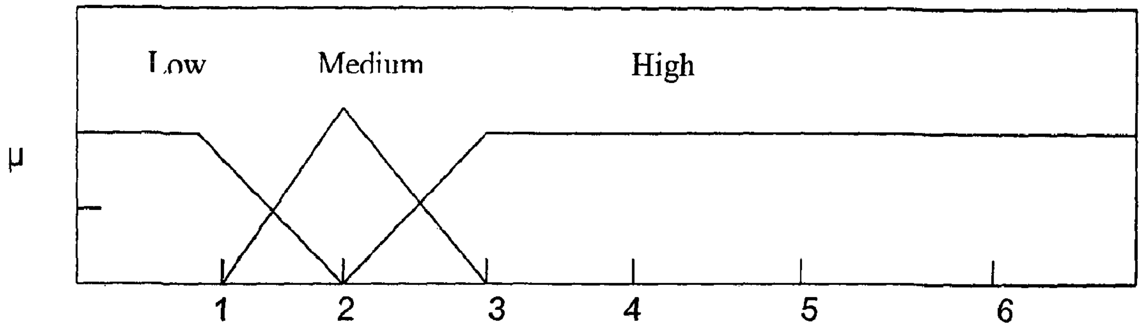


Figure 6. 2 MF of number of BSs(n_{BS})

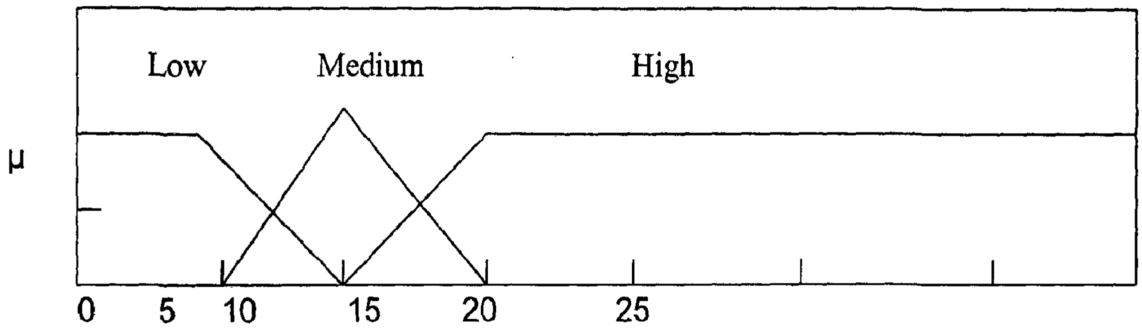


Figure 6. 3 MF number of remaining channels CH_{rm}

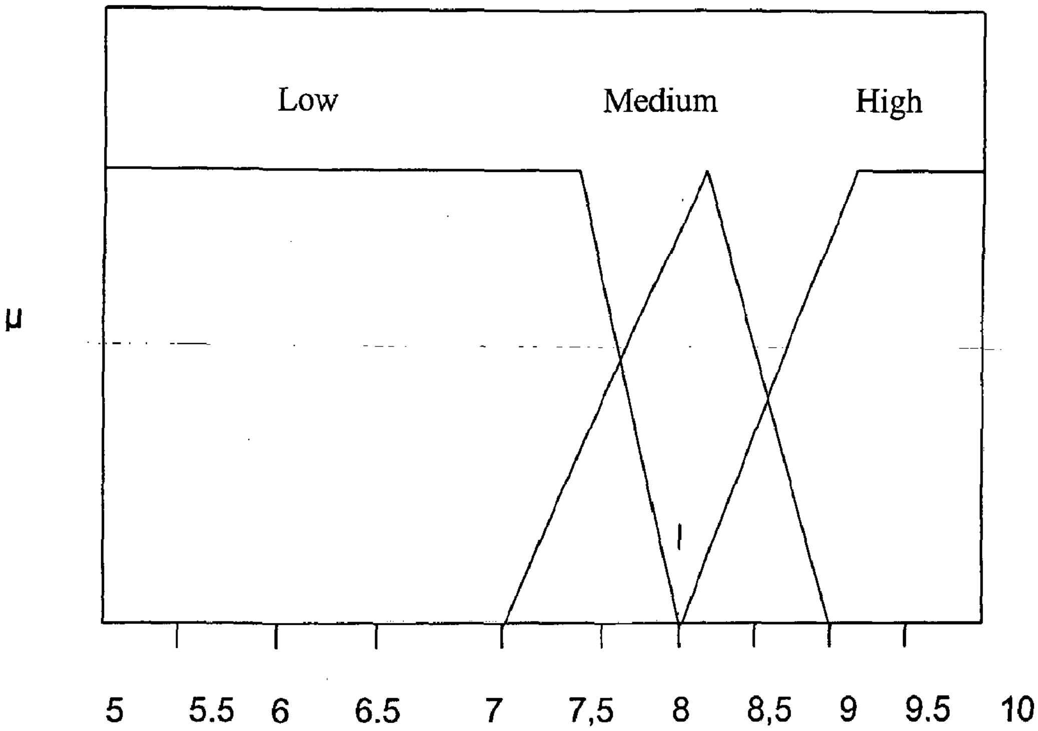


Figure 6.4 MFs of E_b/Io

"15" approximated from 7 multiplied by 2 is assigned to one corner of the triangular MF termed "Medium" and "25" approximated from 7 multiplied by 3 is assigned to one corner of the triangular MF termed "Medium" and one corner of the trapezoidal MF termed "High" "2" and "3" are multiplicative factors of the CH_{RM} and indicate of how many times of base value of the number of the channels are available in "Medium" and "High" CH_{rm}.

ii) Fuzzy Inference: This subprocedure uses "if–then" rules relevant to human-oriented information to properly adapt T_Down. "If-then" rule is as follows –

If E_b/I_0 is A and no_{BS} is B and CH_{rm} is C, then T_Down is D

Where each of A, B, C and D belongs to (Low, Medium, or High) in the fuzzy sets. Therefore, there are 27 rules in the rule base obtained from three fuzzy subsets in each of the three inputs, as shown in Table6.2.

iv) Rule base: There are 27 rules for determining one output from three inputs with three terms in each fuzzy set shown in Table 6.3, T_Down is based on CH_{rm}, which implies traffic loading and the status of the capacity of each BS, and no_{BS}, which implies the pilot strength, the distance from BS, soft handoff area (SHA), and E_b/I_o MS receives.

Table 6.3 Fuzzy Inference Rule Base for Three variables (E_b/I_o, n_{OB}, CH_{rm})

Rule N0	Eb/Io	n_{OB}	CHrm	T_DROP
1	L	L	L	M
2	L	L	M	L
3	L	L	H	L
4	L	M	L	M
5	L	M	M	L
6	L	M	H	L
7	L	H	L	M
8	L	H	M	L
9	L	H	H	L
10	M	L	L	H
11	M	L	M	M
12	M	L	H	L
13	M	M	L	H
14	M	M	M	M
15	M	M	H	L
16	M	H	L	H
17	M	H	M	M
18	M	H	H	L
19	H	L	L	H
20	H	L	M	H
21	H	L	H	M
22	H	M	L	H
23	H	M	M	H
24	H	M	H	M
25	H	H	L	H
26	H	H	M	H
27	H	H	H	M

The algorithm generally aims to achieve the following two objectives:

1) Increase T_Down in order to release traffic channel or channels for serving new and/or handoff call or calls at high traffic load.

2) Decrease T_Down in order to increase the quality of traffic channel at low traffic load.

Aggregation and composition in max–min composition inference, considered in [55] are the procedures for reasoning [50] as described as follows.

V) Aggregation: Aggregation considers each result from each "if–then" rule for all inference rules. For example, let

(n_{oB}=H) P

(CH_{rm}=Low) Q

(E_b/I_o =H) R

(T_Down=High) L

grade of membership function :μ

then aggregation of this rule μ_L =min (μ_p , μ_Q, μ_R) is the fuzzy value of (T_Down=High).

vi)Composition: Composition uses the outcome from the aggregation procedure to compute the fuzzy value of each case of T_Down. Then the final value of T_Down can be calculated by min-max procedure.

vii) Defuzzification: The extraction of the crisp value that represents a fuzzy set from the fuzzy value is defuzzification. It is proposed to apply, the selected defuzzification scheme which is the weight-average formula (WAF).

$$Z_{WAF} = \frac{\sum_{i=1}^{n} \mu_i Z_i^*}{\sum_{i=1}^{n} \mu_i} \qquad (6.1)$$

Where n is the number of MFs for defuzzification. Define Z as a universe of discourse of T_Down. For example, in Figure 6.5, n=3, i.e., "Low," "Medium," and "High, -16<Z<-12, z={z|z ϵ Z}, μ (z) is the aggregated output MF, and μ* is the maximum value of the triangular MF as shown in Figure.6.5, then Z*={ z at the position of each MF| μ (z)= μ*} at the position of each MF . The WAF gives fast computation [50]], which is required by the Soft Hand Off process. When T_Down is obtained after WAF defuzzification, T_Up is calculated by T_Down (dB)+SHW (dB). The SHW denotes the difference between T_Up and T_Down.

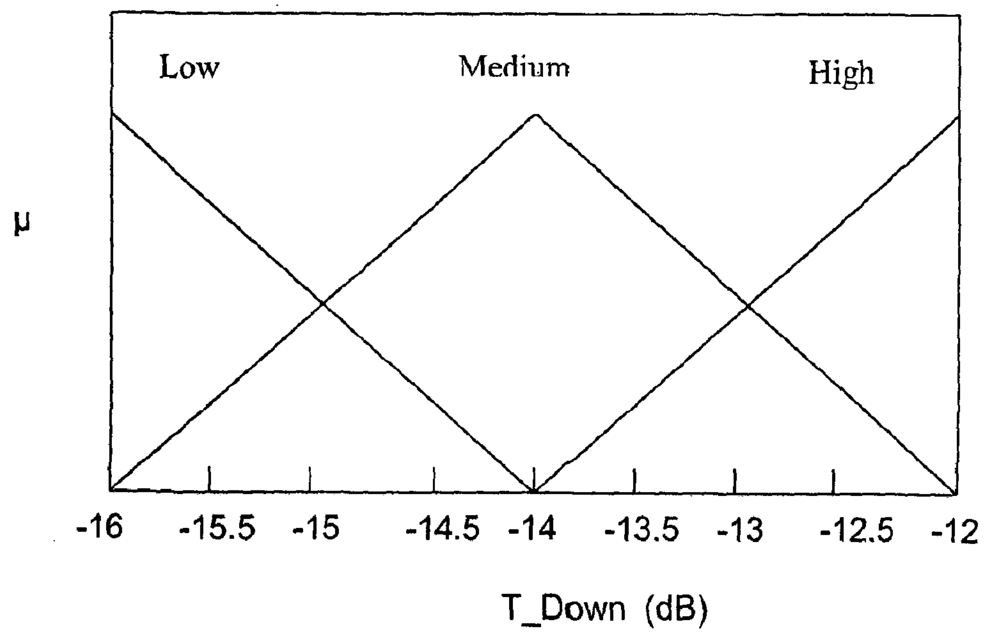


Figure 6.5 MFs of output (T_Down)

6.6 Simulation and Performance Analysis

Let us consider the M number of active mobile users. λ is the average arrival rate of users. $1/\mu$ is the average time per call. The offered average traffic load is λ/μ in Erlang.

The outage probability as shown by Viterbi, A.J is written as-

$$P_{Out} \cong Q\left(\frac{\Delta_r^{'} - (v_f \lambda)/\mu}{\sqrt{(v_f \lambda)/\mu}}\right) \tag{6.2}$$

Where

$$Q(z) = \left(\int_z^{\infty} e^{-\frac{x^2}{2}} dx / \sqrt{2\pi}\right) \tag{6.3}$$

and

$$\Delta_r^{'} = \frac{G_p (1-\eta)}{(E_b / I_0)}, \tag{6.4}$$

$\frac{1}{\eta}$ = The ratio of total interference plus thermal noise power to thermal noise power.

The average user occupancy λ/μ is given as-

$$\frac{\lambda}{\mu} = \frac{\Delta_r^{'} F(B)}{v_f} \tag{6.5}$$

Where $B = \frac{\left[Q^{-1}(P_{out})\right]^2}{\Delta_r^{'}}$ (6.6)

and

$$F(B) = \left[1 + \frac{B}{2}\left[1 - \sqrt{\left(1 + \frac{4}{B}\right)}\right]\right] \quad (6.7)$$

P_{out}= Outage Probability

The probability that the system is blocked, is given by

$P_b = P_r$(N channels are busy)=P(N)

$$P_b = \frac{C_N^M (\lambda/\mu)^N}{\sum_{n=0}^{n=N} C_n^M (\lambda/\mu)^n} \quad (6.8)$$

Where M are number of users.

The parameter E_b/Io varies from 6 to 7dB. In our analysis, we have taken E_b/Io value depending of the bit error rate. The bandwidth is taken as 1228 KHz and data rate is taken as 9.6kbps. The voice activity factor is v_f=0.45. The value of η is 0.1. The processing gain parameter G_p is calculated by the ratio of bandwidth and data rate. The equation from (6.2) t0 (6.7) has been used for performance evaluation of the E_b/Io, outage probability and blocking probability with traffic load. The fuzzy inference system in figure 6.1 gives output T_Down, which is used as the modified value of E_b/Io in equation 6.4 for the analysis. The performance evaluation of E_b/Io, outage and blocking probability is evaluated for the T_Down parameter and compared with IS-95 system as shown in figure 6.1, figure6.2 and figure 6.3 respectively.

6.7 Results & Discussion

The figure 6.6 shows the graph between Eb/Io versus traffic load. The E_b/Io obtained from FIS are improved in the range of 30-50 Erlang traffic load. The graph shows the decrease in the value of E_b/Io at higher traffic load. This lower value of the E_b/Io reduces the interference in CDMA system. Moreover, the values in Eb/Io, in the case of FIS are almost similar to IS-95 in the range 10-30 Erlang traffic load.

The outage probability Pout has been analyzed depends on E_b/I_o. The results of P_{out} are shown in figure 6.7. The outage probability is low for the fuzzy inference system soft handoff algorithm. Eb/Io controlling SHO based on three inputs is improved from IS-95 SHO in the aspect of call quality. This gives higher Eb/Io and lower P_{out} than IS-95 SHO.

The blocking probability P_B is an important performance indicator. The figure 6.8 shows the blocking probability versus traffic load. The P_b obtained from FIS SHO tends to lower as compared to IS-95 SHO. The outage probability for FIS SHO decreases slightly in the low traffic 10-20 erlangs as compared to IS-95. At the medium and high traffic load, the decrease in blocking probability is higher for FIS SHO as compared to IS-95. It is due to the fact that E_b/Io parameter is controlled by the fuzzy system at higher load value.

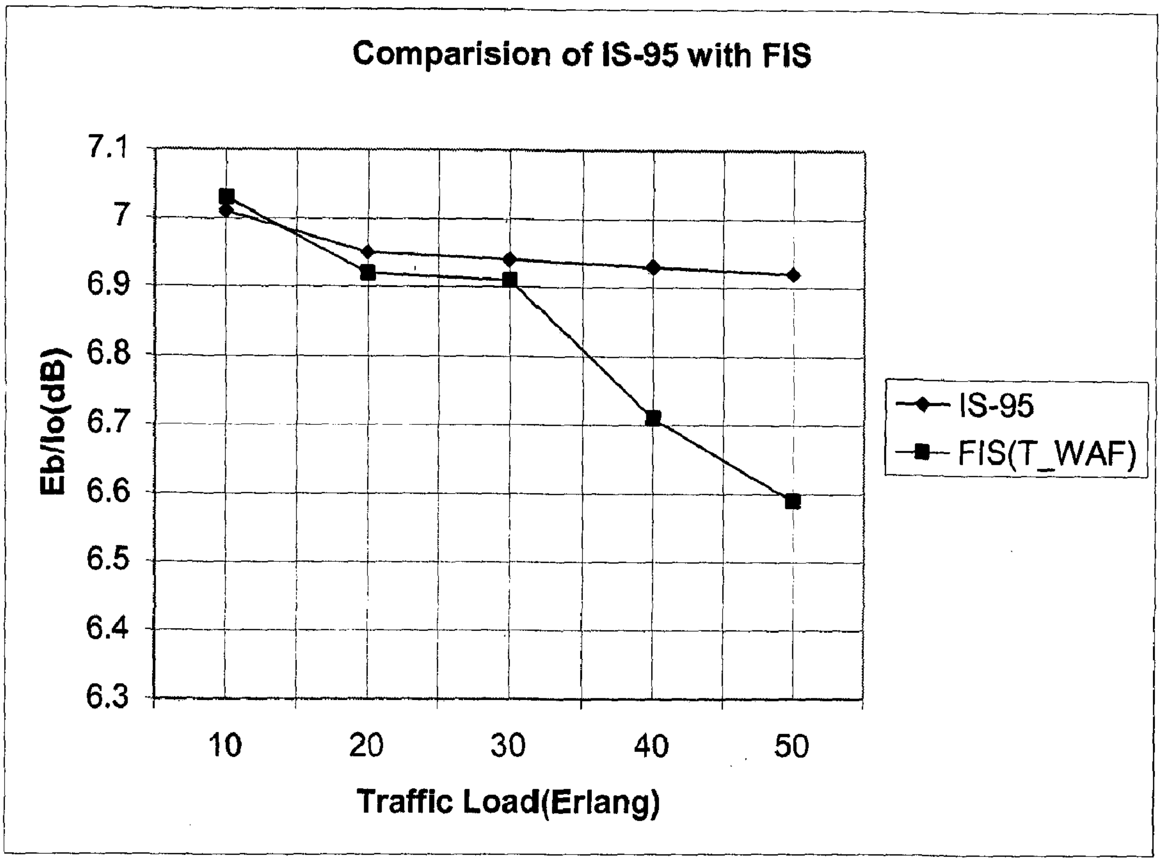


Figure 6.6 E_b/Io versus traffic load

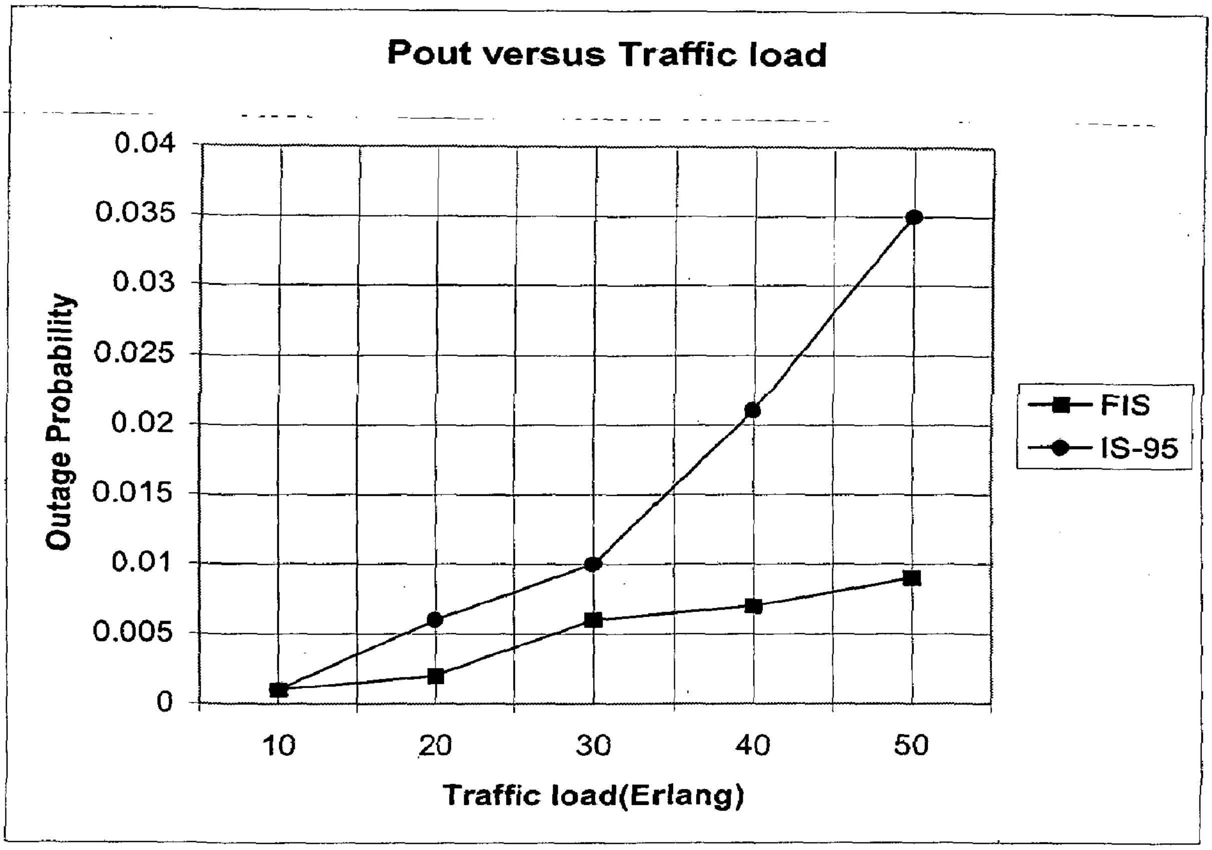


Figure 6.7 Pout versus Traffic load

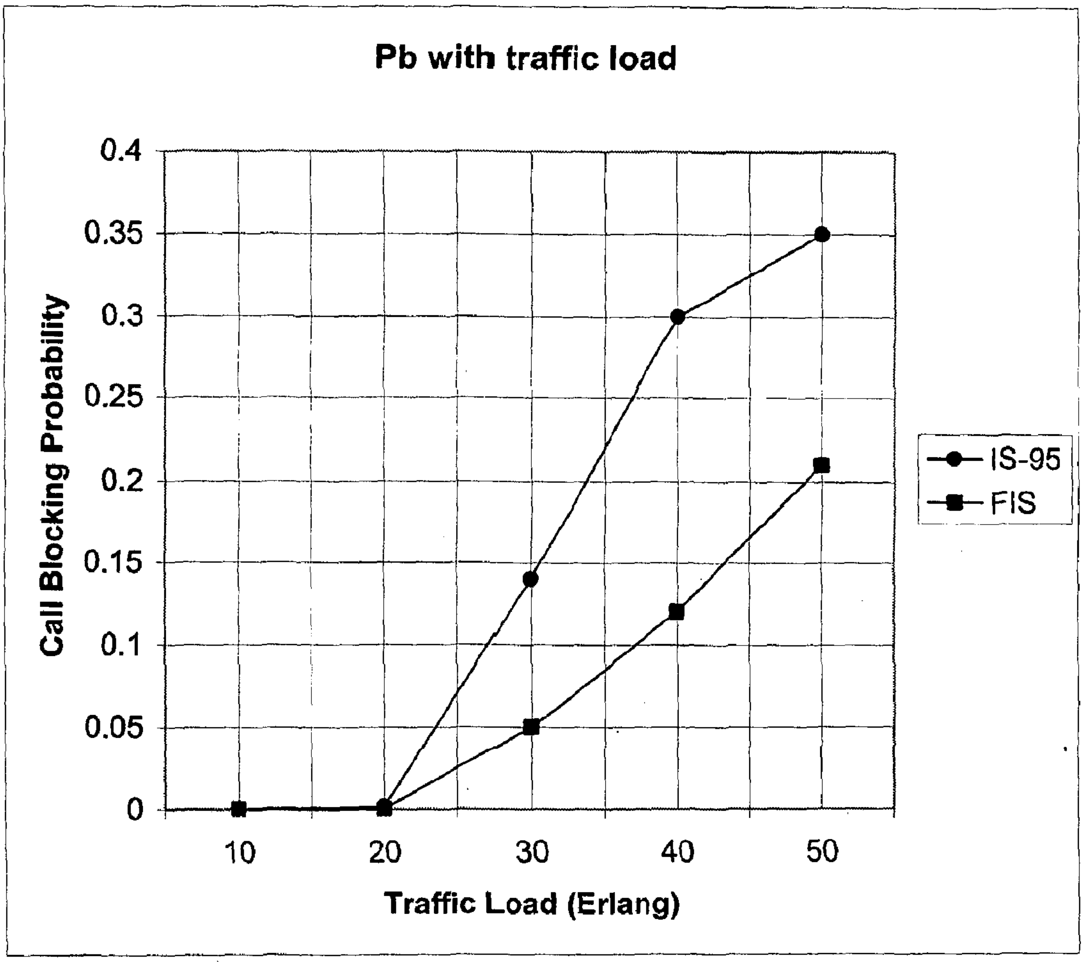


Figure 6.8 Blocking Probability versus traffic load

CHAPTER 7

Conclusions and Scope for Future Work

- Bit Error Rate Analysis of Spread Spectrum and Antenna Diversity
- Performance Analysis of Switched Diversity in CDMA
- Capacity Analysis of Soft Handoff in CDMA With Macro Diversity
- Performance Analysis of Soft Handoff Algorithm in CDMA
- Conclusion and Scope for Future Work

CHAPTER 7

Conclusions and Scope for Future Work

This chapter presented in this thesis summarize the important results of the present work. The scope for future work in the area is also included.

i. Bit Error Rate Analysis of Spread Spectrum and Antenna Diversity

The BER performance of spread spectrum with maximum ratio combining and antenna with selection diversity combining has been analyzed in a multi-path Rayleigh fading channel for two base station diversity configurations. Each base station uses an selection diversity combining (SDC) scheme. It is assumed that each base station receives the same average SNR from a mobile station. For the analysis, the attenuation due to spatial location with respect to the base station is ignored and only the Rayleigh fading effect taken into account. This simplification may have application in the micro-cell environment. On the basis of simulation study for evaluating the bit error rate performance of MRC-SDC configurations has been analyzed . The following are conclusions from the figures(3.4,3.5,3.6):

- The results prove that MRC-SDC technique improves bit error rate performance compared to one MRC or SDC technique.
- With the increase of number of base station the BER performance of the MRC-SDC configuration is improved slightly.

- Probability of error decreases as the signal to noise ratio increases. For lower SNR values (at SNR ≈ 5 dB) the performance for three configurations is almost the same.
- These results can help for providing better QoS and Capacity.
- As the diversity order and number of base station involved increases, the bit error rate performance improved at higher signal to noise ratio.

Scope for future work:

- In this work BER analysis of spread spectrum with MRC and antenna with selection diversity has been carried out. Other diversity combination can be used for this purpose.
- The BER analysis can be evaluated using other modulation techniques like Gaussian Minimum Shift Keying.
- study can be performed for interference suppression for evaluated bit error rate.

ii. Performance Analysis of Switched Diversity in CDMA

The aim of various traditional approach of diversity reception is to improve the bit error rate performance of communication network. The switched diversity is a form of selection diversity in which switching takes place at the threshold level. Fuzzy approaches are very much helpful to deal with threshold level decision. We have proposed the use of fuzzy logic for dynamic feedback threshold control. In the proposed work, signal strength as well as threshold are represented by exponential mathematical functions of fuzzy set. By applying fuzzification, and defuzzification method, the change in threshold can be determined based on received signal strength. After comparing the performance of proposed scheme with constant threshold schemes, the following are the conclusions:

- QoS parameters i.e bit error rate is the function of signal strength and the threshold level
- A comparative study has revealed the proposed scheme is able to achieve lower bit error rate and higher signal strength than the constant threshold schemes.

Scope for future work:

- The work presented in this chapter is based on equal signal strength in all the branches. This assumption can t be eliminated to analyze the system behavior correctly.
- We have used switched diversity of two branches only, more than one branch can be used for the purpose of bit error rate analysis.
- In proposed fuzzy scheme, exponential membership functions can be replaced by other functions to achieve better performance.

iii. Capacity Analysis of Soft Handoff in CDMA With Macro Diversity

In this work, the effect of soft handoffs on the system capacity of CDMA systems by using an average bit energy-to-interference. The capacity in terms of maximum number of users per cell is calculated mathematically. We considered the capacity with diversity and capacity without diversity with the voice activity factor. After analyzing the results, the conclusions based on the comparative performance are as follows:

- The capacity as number of users increases with macro diversity as compared to capacity without macro diversity.
- The capacity gain due to macro diversity is 7.0% or 6.1% for VAF's of 3/8 and VAF 1/2, respectively
- The results shows that the capacity decreases with increasing interference.
- The excess capacity due to macro diversity is due to an improvement in communication quality for mobiles in soft handoff.
- The results showed that there is tradeoff between the capacity, signal strength, voice activity factor

Scope for future work:

- We used soft handoff using two base stations for capacity analysis. We can analyze using more than two base stations involved in soft hand to see the effect of bit error rate performance of Communication Network.
- In our analysis, we have assumed path loss exponent value of four. The similar analysis can be done by assuming other path loss model like Hata model.
- Work can be extended to analyze the effect of other cell interference.

iv. Performance Analysis of Soft Handoff Algorithm in CDMA

The soft handoff algorithms start handover process at the threshold value of the parameters. The soft handoff threshold parameters can be fixed or adjusted dynamically. We considered three fuzzy variables namely, bit energy to interference ratio, number of base station and number of channel. After fuzzification and defuzzification process, we find the value of T_Drown for soft handoff decision. After applying the scheme, the conclusion based on comparative performance are as follows.

- The proposed three input fuzzy scheme results are given in terms of signal to noise ratio, outage probability and blocking probability with traffic load,as compared to two input fuzzy Inference System.
- when the additional input E_b/I_0 is applied as a third input to the fuzzy inference system, it leads to significant decrease in call blocking probability and the outage probability.
- Change in the value of probabilities that there is a need of careful determination /implementation of number of inputs to the fuzzy inference system.

Scope for future work:

- Soft handoff algorithm can be implemented after careful selection of input parameters.
- Combination of other schemes like channel borrowing during handoff process can be analyzed for QoS parameters.
- various parameters used in this algorithm can be calculated and loaded into look-up tables to facilitate dynamic threshold allocation.

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